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FRDA REPORT 025

EVALUATION OF SOIL DEGRADATION AS A FACTOR AFFECTING FOREST PRODUCTIVITY IN BRITISH COLUMBIA
A PROBLEM ANALYSIS PHASE I

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March 1988

ABSTRACT

PREAMBLE

Soil degradation is a term used to describe the loss of productivity caused by soil disturbance resulting from forestry practices employed during tree harvest, site preparation or stand tending. The issue is three-fold. First, areas being reforested today (including backlog NSR) may be influenced by soil disturbance from harvesting activities and require special rehabilitative measures. Second, treatment of these previously harvested sites by means of mechanical, chemical and prescribed fire techniques may impart degrading effects on the soil. Third, forestry practices currently being employed to harvest the stand and prepare the site for regeneration, may be adding to the area of sites already influenced by soil degradation.

OBJECTIVES

The overall objectives of this study are to outline the areas of greatest impact, to demonstrate the necessity for research and survey expenditures, and to provide a basis for prioritization of such expenditures. This report is Phase I of the overall project. It identifies the causes, nature and extent of soil degradation on forest land in B.C. and provides an estimate of the potential loss of productivity. Phases II and III of the project will be completed in 1987/88.

METHODOLOGY

Data and information were gathered by four principal methods:

1. Literature review.
2. Questionnaire sent to industry and government personnel.

3. Interview and discussions with individuals involved in soil degradation research.
4. Summary data provided by the Ministry of Forests and Lands.

Only information and summary data for the time period 1976 to 1985/86 were collected and analyzed.

CONCLUSIONS AND RECOMMENDATIONS

The study has shown that of all forest harvesting techniques, ground skidding has the greatest potential to impart soil degradation. Of all site preparation techniques, windrowing and blade scarification are considered the most significant in regard to soil degradation. This study estimates that approximately 400,000 ha of degraded forested soils have been created by forestry practices in the Province between 1976 and 1985/86. It is estimated that over 20% of the area harvested during that period has been degraded.

The potential reduction of productivity resulting from soil degradation created by forestry practices over the ten year period (1976-1985/86) is conservatively estimated at approximately 400,000 cubic metres annually. This translates to an annual loss to the provincial economy of approximately 80 million dollars (assuming $200/m^3). A liberal interpretation of available data suggests that the present annual loss to the provincial economy as a result of forestry practices between 1976 and 1985/86 is approximately 126 million dollars. The annual productivity loss resulting from soil degradation is estimated to be increasing by 50,000 cubic metres or 10 million dollars per year. If present forestry practices continue, the annual loss may double in less than ten years.

Costs for rehabilitating productivity on degraded forest land are estimated to be in the range of $500 to $5,000 per hectare. However, rehabilitation seldom fully recovers the original site productivity. Costs for prevention or reduction of soil degradation are estimated at between $250 and $1,800 per hectare through the use of alternative harvesting systems and between $0 and $200 per hectare for the improvement of pre-harvest planning. Significant reduction of harvesting degradation can be accomplished with no increase in costs.

Depending upon the economic models used, rehabilitating degraded soil may or may not be cost justifiable. Some alterations of harvesting systems appear to be cost justifiable for avoiding or reducing soil degradation. All research results appear to corroborate that the prevention of soil degradation is more effective and far less costly than rehabilitation. Improved planning is viewed as a cost-effective means of reducing future soil degradation.

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1.0 INTRODUCTION AND STUDY OBJECTIVES

This report has been prepared in response to a request from the Canadian Forestry Service, through the auspices of the Canada-B.C. Forest Resources Development Agreement (FRDA), to evaluate soil degradation as a factor affecting "Not Satisfactorily Restocked" (NSR) backlog forest lands in British Columbia.

The specific objectives of this study are to identify the nature and extent of soil degradation on forest land in B.C. and evaluate its effects on regeneration/plantation performance, and to recommend procedures needed to improve soil management and forest regeneration procedures. Where information is lacking, recommendations will be made for specific research projects to fill those gaps.

The overall study encompasses these two specific objectives by subdividing the tasks into three phases. These three phases and their sub-objectives are briefly outlined as follows:

PHASE I

a. Outline the causes, nature and extent of existing soil degradation in B.C. resulting from forestry operations.

b. Evaluate the relationship between soil degradation from forestry operations and existing NSR land.

c. Express the potential loss of conifer productivity from soil disturbance on existing NSR land in terms of land area impact, volume loss, and dollar loss on a regional and provincial basis and evaluate the implications of such losses in terms of the provincial AAC and the economic health of the province.

d. Assess the feasibility of, and probable costs associated with rehabilitating productivity and/or regenerating productive coniferous stands on severely disturbed forest land.

PHASE II

Outline appropriate research needs and strategies to develop and assess:

a. Effective site rehabilitation measures;

b. Appropriate soil management techniques;

c. Efficient monitoring systems and programs; and

d. Appropriate harvesting and site preparation technology.

PHASE III

a. Evaluate the effectiveness of current site degradation and rehabilitation regulations, legislations and policy, and the implementation thereof.

b. Evaluate the adequacy of government and private sector staffing levels to deal with site/soil degradation problems.

c. Evaluate government and private sector training needs.

Only Phase I is the subject of this report. The results of this report and subsequent discussions with the review agencies (Ministry of Forests and Lands, and Canadian Forestry Service) will be used to help formulate more succinct terms of reference for Phases II and III of the problem analysis. It is currently understood that Phases II and III will be undertaken and completed in fiscal year 1987/88 as part of the overall contract.

It is necessary for the reader to be fully aware of the intent of this report. The purpose of this report is to examine existing information and knowledge to provide insight into the nature and extent of the soil degradation/forest productivity issues. The results of the study are intended to guide and direct future work on the subject in such a manner as to focus attention on the most significant issues.

While the subject of soil degradation as a factor affecting NSR backlog forms a significant part of this study, it does not constitute the overall scope of the work. Rather, the subject has been considered as it relates to all of the forest land base in B.C., not just that land designated as NSR. This broad scope facilitates a comprehensive analysis and discussion of the topic.

Two other aspects related to the scope of this project need to be understood. First, the term 'soil degradation' by definition connotes negativity. Consequently, much of the discussion in the following report may seem at first glance to be overly pessimistic and negative. However, this is not the authors' intent. We believe that the subject is, in actuality, a positive one in that by understanding and resolving issues of soil degradation the productivity of the forest land base can be maintained for the overall benefit of society. We have strived for objectivity in order to provide a body of information which is of value to government and industry, and hence society as a whole. We have not entered into any detailed discussion or recommendations regarding how the costs (and benefits) of soil degradation should be shared. Rather, we have presented our findings and results on a generic basis in order for them to be used in a cooperative fashion between industry and government. Second, we have ascertained that the current understanding of the full scope of the soil degradation/ productivity issue is in a deplorable state throughout the Province. This statement may appear at odds with the number of research papers and reports presented in the bibliography on the subject. While each of these studies has great value in its own right related to specific soil degradation and soil disturbance issues there is a very significant lack of understanding regarding how to apply the results in a meaningful and comprehensive (province-wide) fashion. This is particularly acute regarding the relationship of soil degradation effects on productivity.

Specifically, there is a very real and, we believe, a potentially damaging lack of coordinated effort to minimize soil degradation, to rehabilitate degraded soils and to research and adequately address the problem. We believe that there is real need to facilitate a common approach to solving the problems of soil degradation by industry and the two levels of government so that the results can be used in a positive environmental, economic and social framework.

The study was conducted under the guidance of Dr. Richard Smith and Mr. John Senyk (CFS) and Mr. Gerry Still (MoFL). Mr. Greg Utzig and Mr. Mark Walmsley prepared specific sections of the report. Many others contributed their ideas and information, and suggestions regarding the content of the report. While their valuable assistance is greatly appreciated, there simply are too many to list here. Any errors or omissions are the responsibility of the authors.

2.0 METHODS OF STUDY

2.1 INTRODUCTION

The primary objective of the problem analysis is to identify the nature and extent of soil degradation on forest land in B.C. and evaluate its effect on regeneration/plantation performance. In order to achieve this objective, it was necessary to gather and analyze existing information on the broad, or general, aspects of the problem and then focus the investigation on specific issues (many of these specific issues, however, will be dealt with in Phases II and III of the overall project). One of the most valuable aspects of the data and information gathering process was the direct consultation component of the work with individuals directly involved with soil degradation research and forestry managers/staff in industry and government who have some knowledge and experience related to the issues.

A literature review was undertaken and accomplished by several means. A computer search was made to identify pertinent scientific articles. Through the use of a questionnaire, key individuals throughout the Province were canvassed for reports and articles they either had in their possession, or could direct us to. As part of the questionnaire process, respondents listed scientific papers and research reports which they deemed valuable to the study. By means of this process, a comprehensive collection of reports/papers was assembled and reviewed. The bibliography (Chapter 12) contains a listing of those articles which were utilized during the study.

The questionnaire used to ascertain the nature and extent of concerns, data sources and professional judgement from a variety of forest research scientists and forest land managers in both government and industry is contained in Appendix I. Response to the questionnaire, which was circulated province-wide, was positive in that the majority of questionnaires were returned. The purpose of the questionnaire was not that of an `opinion poll' but rather that of information and idea gathering. The questionnaire responses helped focus the study by identifying specific issues and knowledgeable individuals. Several respondents questioned the value of the questionnaire, stating that erroneous or incorrect interpretations of the information provided could result. We recognized this concern and have not used the information provided in any conclusive or statistical fashion unless it was corroborated by other research findings.

Our work in obtaining data on forest harvesting practices and silvicultural treatments on a provincial basis required contact with a number of Branches of the Ministry of Forests and Lands (most notably: Engineering, Research, Silviculture, Planning and Inventory, Valuation and Protection). Contacts were made in Victoria, and more specifically in Regional and District centres throughout the Province. The data gathered in this fashion were, for the most part, summary information for entire Forest Regions or the Province as a whole. Since we have no means of checking these data, we have relied on its accuracy relative to the overview purpose to which we have applied it.

In addition to the very significant research results provided by research scientists and foresters in the U.S. Pacific Northwest, two other sources of data and information proved valuable to our work. First, data and results from industrial and government research foresters and managers related to studies that have been conducted in the Province. Second, a number of the papers presented at the Tenth B.C. Soil Science Workshop (February 21, 1986) proved most instructive. While these papers are still unpublished and in draft form they were made available to us by Dr. Dan Lousier (Ministry of Forests and Lands, Research Branch). For the most part, they constitute the state-of-the-art in B.C. regarding the subject of site disturbance and soil degradation.

We have relied on data provided to us from the Ministry of Forests and Lands and utilized it extensively in our analysis. In this regard it is important to point out that there is a serious lack of long-term data and information regarding forestry activity in the Province. We have therefore been forced to piece together bits of data from various sources which, in some cases, do not always corroborate each other. However, it is our opinion that the results of the data analysis reported in subsequent chapters of this report are meaningful in the context of evaluating general trends and averages.

2.2 CALCULATIONS OF AREA DEGRADED AND PRODUCTIVITY LOSSES

The primary data source for the estimates of the area of forest soils degraded and the resulting productivity losses was the Ministry of Forests and Lands annual reports (MoFLAR). Data from the MoFLAR's was broken into treatment and slope classes by combining it with data from Valuation Branch harvesting studies and the Silviculture Branch site history records.

Relevant literature was reviewed to establish which forestry practices contribute to soil degradation and what percent of the areas treated by those practices was likely to be degraded. Based on this review, the authors established percentages for each practice to calculate the total area degraded by forestry practices between 1976 and 1985/86.

Based on further review of the literature, percentage growth losses were estimated for degraded soils associated with each type of disturbance. These percentage reductions were then applied to the mean annual increments (MAI) for the various Forest Regions and multiplied by the areas of degraded soils calculated previously. These numbers were then multiplied by an estimated economic value to arrive at the cost to the provincial economy.

The general lack of data and the scale of a provincial calculation has created the need for various assumptions on the authors' part. The calculations presented in Chapter 5 and 6 reflect conservative assumptions which are explained in those chapters. Appendix II presents the results of using more liberal assumptions.

3.0 SOIL DEGRADATION: DEFINITION OF TERMS AND CONCEPTS

3.1 INTRODUCTION

Soil is one component of the environment which is essential for human survival and provides economic opportunities for growth and development (other factors being water and climate). Hudson (1981) discussed this issue from an historical perspective by outlining evidence that soil quality often played a key role in the growth and decline of early civilization. The context of this evidence is important since British Columbia's wealth is based upon the vast forests nature endowed it with. In this historical context, it is perhaps instructive to note that while soil degradation has been a topic of concern and research in the U.S. since the 1940's, similar recognition in B.C. did not occur until the 1970's.

While soil depletion and degradation are of concern to a variety of economic activities (agriculture, fisheries, wildlife) this study focuses specifically on the forest resource and does not discuss other resource values. We are investigating the actual site effects of soil degradation on commercial forest regeneration and plantation performance (productivity) and not the effects of processes such as siltation on fish bearing streams, loss of recreational values or nutrient/chemical effects on water quality. The issue of soil degradation/forest productivity has been addressed on a provincial basis using summaries for the various Forest Regions or the Province. While site specific or local data and concerns may become masked by using provincial means or averages, significant trends can be established which will aid in directing more detailed analysis.

3.2 DEFINITION OF TERMS

It is critical to note the distinction between site and soil. A site is a naturally functioning ecosystem which is uniform in climate, parent material, physiography, soils, vegetation and animals. One site is distinguished from another site by dissimilarities in biogeochemical cycling and energy exchange among the above noted components. Soil is one component of a site that provides a storehouse of water and essential nutrients for tree growth as well as the physical means of supporting the tree.

Further, it is important to distinguish between degradation and disturbance. Soil disturbance generally refers to visible physical changes in a soil from its natural state (e.g. exposed or mixed mineral soil horizons). Severe soil disturbance is often equated with soil degradation (e.g. very deep gouging). Degradation is any change in physical, chemical or biological properties which reduces productivity. Disturbance may be an indicator or a means of measuring degradation but not always. Some types of soil disturbance can in fact produce positive effects on productivity (e.g. shallow mixing). Degradation results from abrupt changes caused by both natural processes (erosion, flooding) as well as human activities (road construction, prescribed burning). Erosion related soil degradation can also lead to off-site damages such as stream sedimentation or road washouts. Off-site damages are not considered in this study. The scope of this report encompasses only the examination of soil degradation as it relates to forestry operations including both harvesting and silvicultural treatments. Further, the term degraded soil is not to be confused with the use of the same term in a pedological sense, where degraded refers to soil weathering and leaching.

The following list provides definitions for factors affecting soil degradation as used in this report.

Soil Compaction and Puddling

Soil compaction is an increase in bulk density, a decrease in total pore space and non-capillary pore space, an increase/decrease in capillary pore space and depending upon compaction force, a decrease in infiltration rate, permeability and effective pore diameter. Puddling is a change in soil structure from granular to massive. Subsequent changes to soil thermal properties may also result.

Soil Erosion

The removal of soil material by means of water, wind or gravity. Includes both mass wasting and waterborne surface erosion.

Soil Displacement

The mechanical movement of soil by man's influence from one area to another. For example, the excavation required to construct a skidroad on sloping ground. Other examples include windrowing and stumping (stump extraction) which can drastically disrupt soil horizons. The term `scalping' is often used in this context and includes the loss of surface organic horizons.

Soil Water Availability

Change in available water storage brought about by changes in bulk density and subsequent modifications to pore space and permeability. Subsequent changes to soil thermal properties may also result. Soil water availability can also be reduced by disruption of subsurface water movement (seepage interception).

Loss of Organic Matter and Soil Nutrients

The removal or displacement of surface organic layers from the soil by mechanical (scalping), fire or chemical means and the subsequent loss of soil nutrients. The effects of nutrient loss caused by mineral soil leaching and mineral soil displacement are also considered in this category. Net reductions in vegetation production, litter fall or changes in decomposition rates can also reduce organic matter contents of the soil.

Changes in Soil Acidity

Increase or decrease in soil pH and the subsequent influence on nutrient availability and losses of nutrients due to leaching. An example would be the exposure or mixing of calcareous soil horizons with near neutral surface horizons.

Changes in Soil Biology

Decrease in mycorrhizal formation and changes in species and/or populations of soil bacteria, fungi and actinomycetes and the concomitant impact on decomposition, and nutrient cycling and availability.

3.3 RELATIONSHIP OF FOREST SOIL AND AGRICULTURAL SOIL DEGRADATION

The major impetus for undertaking this study is the need to quantify forest soil degradation effects on productivity on a regional scale, such as has been done for agricultural soil degradation. The Select Standing Senate Committee on Agriculture, Fisheries and Forestry (1984) stated the following:

> "The Standing Senate Committee on Agriculture, Fisheries and Forestry has travelled extensively in Canada examining the issue of 'soil degradation', a problem which is already costing Canadian farmers more than $1 billion per year in farm income. It has determined that we are clearly in danger of squandering the very soil resource on which our agriculture industry depends."

This recent report on agricultural soils, coupled with current research information on forest soils, indicates that soil degradation precipitated by some forest management practices may be resulting in significant adverse effects on site productivity.

However, there are a number of things which differentiate forestry from agriculture in the context of soil degradation and producttivity. Forestry operations generally require only two or three entries onto the land per rotation thereby reducing chances of soil degradation. However, this also reduces the opportunities for measuring crop performance and rectifying identified problems. In contrast to agricultural crops, which are usually harvested annually, the harvest interval for forest crops is much longer (50 to 150 years). This has often lead us to believe that nature and time will heal the soil degradation `wounds' caused by forestry operations. While this may be the result in some cases, it is not generally true.

Productivity losses from degradation will become even more crucial as the Province moves to second growth stand management. For example, a portion of a plantation suffering reduced growth due to soil degradation, may result in trees on the degraded area being of non-commercial size at the culmination age for the plantation. In this case, there is not simply a percent productivity reduction relative to the area degraded, but in effect a total yield loss for the degraded area. The alternative of uneven-aged forest management may cause additional soil degradation by increasing soil disturbance and compaction. Multiple entries with machinery during the growth cycle is certainly a factor which is recognized in agricultural soil degradation.

Two other aspects related to forestry in B.C. should be recognized. First, B.C. is unique in Canada since it has the most diverse and complex landform and climate patterns. The Select Standing Senate Committee (1984) described B.C. as follows:

> "The physiography of the province, coupled with the variations in the climate, bestow upon British Columbia virtually all of the soil degradation problems found in the rest of the country and a few more besides."

In contrast to agriculture, forestry occurs on a great number of these diverse landscapes resulting in the fact that forest management must accommodate great biogeoclimatic diversity. Further to this, more forest harvesting in the province is occurring on potentially sensitive sites. That is to say, with the completion of the first cut on more easily accessible, valley bottom lands, forestry operations have progressively moved onto higher elevation, more steeply sloping lands which are more vulnerable to degradation. This trend tends to increase the emphasis on the issue of soil degradation and maintenance of productivity.

3.4 SOIL DEGRADATION/FOREST PRODUCTIVITY INTERRELATIONSHIPS

It is not safe to simply assume that site degradation is a result of soil degradation alone and therefore by controlling soil degradation one can maintain site productivity. The fact is that numerous variables may simultaneously affect the biological processes of the forest and hence have an influence on productivity. As discussed by Ballard (1986), McNabb (1986) and McNabb and Campbell (1985) utilizing measurements of productivity to determine the degree of soil degradation ignores the influence of other site variables and their interrelationships (e.g. plant competition). When we measure productivity, we are measuring the net effect of all variables. To measure soil degradation by means of growth and yield models we must hold all other variables constant. Unfortunately, this is extremely difficult to do. This concept is important to note in the context of research results which have shown increased growth on some sites which have been disturbed (Smith and Wass 1979, Ballard 1985). In these cases, harvesting or site preparation may have negatively influenced soil fertility but the net result has been improved performance when comparing disturbed and undisturbed sites. Improvement of other site factors affecting seedling growth may have compensated or masked the soil-related influences. In these cases, the negative influence of soil degradation is often ignored. However, if seedling performance appears better on disturbed vs undisturbed sites, perhaps the increase could be greater were we to understand the relationships inherent in the biological environment of the tree.

An additional consideration is that the only true measure of forest productivity is one that is based on data from a full rotation. Short-term measurements of seedling survival and growth are insufficient to obtain a true indication of the impacts of soil degradation on productivity.

When considering the relationship of soil disturbance to soil degradation, it is important to appreciate that the same degree of soil disturbance on two different sites may have quite different results in terms of soil degradation. For example, given the same degree of disturbance, a fine textured soil will exhibit greater bulk density increases than a coarse textured soil. Therefore, the fine textured soil has a greater likelihood of suffering some degree of soil degradation. This is a simplistic example of a complex situation which has both short-term as well as long-term implications. Soil degradation, in some circumstances, may not exhibit a linear relationship with time throughout the full rotation age of the stand due to ameliorating effects.

Such complexities point to the fact that site specific data and information is valuable when examining soil degradation/productivity relationships. In fact, this aspect is one which has been of most concern to the authors of this report. As a result of the paucity of research data on the topic, we have been forced to apply the results of a few research findings (some, in fact, imported from the U.S. where soil conditions may be quite different in comparison to B.C.) to entire forest regions and the Province as a whole. One can perhaps argue that by broadening or generalizing the results on this basis it is possible to overcome the influence of small, insignificant variables, but the cumulative effect of compounding errors can often lead to quite erroneous results.

Moon (1986) expressed this problem succinctly. He points out that there is a lack of either theoretical or empirical models to measure the phenomenon of soil degradation. In this absence, he notes, one is left with expert opinion or expert systems models. In our analysis of available data and research findings we have relied on expert interpretation of the results and opinions provided to us by professional foresters and soil scientists. Whether judged good or bad, this is the present state of understanding in British Columbia. Consequently, it is necessary to understand this situation when utilizing the results of this study.

3.5 ECONOMIC EFFECTS OF SOIL DEGRADATION

Estimates of growth reduction resulting from soil degradation provided by research studies may be viewed as conservative by some and liberal by others. However, the fact remains that whatever figure is used it must be dealt with on an economic basis if we are to even come close to answering the question of "What is the cost of soil degradation"? This question is worthy of an answer if we are to determine how much we are willing to pay to either avoid soil degradation in the first place or to rehabilitate existing and future degraded soils. The definition of the term `we' as used in the previous sentence is in need of clarification. If `we' is the landowner (in B.C., the Ministry of Forests and Lands as the manager of public forest lands) then a much broader and longer term view, which must weigh tangible and intangible costs/benefits carefully, is necessary when compared to the situation when the `we' is a private firm (forest products company). Should the `we' be defined as society, then a myriad of concerns (short and long term, tangible and intangible, on-site and off-site) come into play, and expenditures are more clearly justifiable.

Despite these problems, the issue of cost evaluation remains. However, it can be concluded that there are presently no empirical data upon which to base an economic evaluation of the effect of soil degradation on forest productivity in the Province of B.C. Regardless of this, some attempts have been made by various researchers (Bowden 1986, Routledge 1986, Carr 1985a, Reed 1987). The majority of this work entails dealing with problems in the present which may have economic consequences in the future. Generally, they have taken two approaches. The first is a conventional economic evaluation which takes the decline in net returns to the site at a specified time and discounts it to a present value equivalent. Such an analysis is usually termed 'net present value'. The results of such analyses are very dependent on what is assumed about future values, the time frame chosen (time of harvest) and the appropriate discount rate. The latter item, discount rate, being perhaps the most significant variable.

The second approach has generally been one which examines costs by way of an 'Allowable Cut Effect.' This approach assumes that the loss in forest productivity requires a reduction in the 'Annual Allowable Cut (AAC)'. This approach produces more immediate and quantifiable results and partially relieves the economist from having to deal with such weighty issues as long-term forecasting.

While economists appear to be split on this issue, one thing is clear. Foresters, soil scientists and others must provide an adequate understanding of the effects of soil degradation on forest productivity. In the absence of empirical models which will allow us to accurately predict these relationships, the economist is unable to undertake an acceptable and meaningful analysis.

The objectives of this study did not include an exhaustive economic evaluation of the soil degradation/forest productivity relationship. Rather, they required that, on a Provincial and Regional basis, the study address the loss of productivity in terms of volume/area loss and to evaluate the implications in terms of the Provincial AAC. This evaluation has been undertaken and has been reported on in various sections of this report. However, it should be noted that the calculation of AAC made by the Province contains some reduction for items such as roads, skid roads and landings. The actual percentage figure varies throughout the province, according to individual Timber Supply Area (TSA) and Tree Farm Licence (TFL) analyses. Consequently, it is not reasonable to apply figures developed for reduction of productivity stemming from soil degradation, to the present figure for committed AAC since a double-reduction may take place in some circumstances. For a comprehensive evaluation, analyses are required on a management unit basis (e.g. TSA or TFL).

4.0 LITERATURE REVIEW

The objectives and scope of this phase of the project did not require a written review of the literature dealing with soil degradation. While preparing the report, a number of existing review papers on the various aspects of soil degradation were encountered. To offer the reader an opportunity to explore some topics in more detail, a list of papers offering an overview are listed below. For more specific studies the reader is referred to the bibliography in chapter 12 of this report, or the bibliographies of the papers listed below.

SOIL DEGRADATION CONCEPTS

Ballard, T.M. 1986; McNabb, D.H. and H.A. Froehlich. 1983.

FOREST MANAGEMENT IMPACTS IN GENERAL

Switzer, G.L., D.M. Moehring and T.A. Terry. 1978; Lavender, D. and M. Newton. 1985; Standish, J.T. *et al.* in press; Weetman, G.F. 1983.

HARVESTING IMPACTS

Cromack, K.Jr., F.J. Swanson and C.C. Grier. 1979; Smith, R.B. and E.F. Wass. 1976; Utzig, G. and L. Herring. 1975.

SILVICULTURE IMPACTS

Ballard, T.M. 1986; Haines, L.W., T. E. Maki and S.G. Sanderford. 1975; Perry, D.A. and S.L. Rose. 1980.

PRESCRIBED BURNING

Feller, M.C. 1982; McNabb, D.H. 1986.

COMPACTION

Carr, W., R. Frank, and S. Norman. 1985; Greacen, E.L. and R. Sands. 1980.

REHABILITATION

Carr, W. 1980; Miles, D.W. and Froehlich, H.A. 1986; Terry, T.A. and R.G. Campbell. 1981.

PREVENTION AND SKIDROAD PLANNING

Froehlich, H.A. and D.H. McNabb. 1983; Garland, J.J. 1982; Hammond, H.L. 1982.

COSTS OF SOIL DEGRADATION

Hammond, H.L. 1986a and b; Routledge, R.D. 1986; Schwab, J.W. 1986.

5.0 CAUSES, NATURE AND EXTENT OF EXISTING FOREST SOIL DEGRADATION

5.1 INTRODUCTION

Soil degradation, as previously defined, has been shown by various studies to result from a variety of management treatments commonly applied to the forest lands of B.C., as well as from natural erosion processes which can be accelerated by these management treatments. The various treatments which have been shown to cause soil degradation will be discussed in section 5.2, in relation to the types of degradation they cause. Section 5.3 will give a summary of the areal extent of these treatments, and an estimate of the land area degraded by these activities. The potential impacts on productivity will be discussed in Chapter 6.

5.2 FOREST MANAGEMENT ACTIVITIES RELATED TO SOIL DEGRADATION

5.2.1 Harvesting

Haulroads, skidroads, landings, and yarding can create soil disturbance ranging from 6 to 87% of the harvested area (see table 5.1). In B.C., roughly 20% of the area annually harvested is done so with cable systems and 80% with ground-based systems (i.e. skidders or crawler tractors). However, because of the higher per hectare volumes on the coast where most of the cable systems are used, 40% of the volume is logged by cable systems and 60% by ground skidding systems. Both types of harvesting systems have been shown to create significant areas of disturbed soils, but the cable systems generally have less impact.

Both ground based and cable harvesting systems have been shown to create areas of degraded soils as a result of compaction, soil displacement, scalping and associated erosion (Bockheim *et al.* 1973, Schwab 1978, Utzig and Herring 1974). The primary source of soil degradation in harvesting is the construction of roads and

Table 5.1: Area disturbed by various harvesting systems, as a percentage of the harvested area.

UNDIST	SL DIST	DEEP DIST	COMPACT	UNSP DIST	SOURCE
GROUND SKIDDING - SUMMER					
*	29	58	*	*	Bockheim *et al.* 75
62	*	38	*	*	Carr & Mitchell 86
*	*	*	*	19	Cantlon 86
*	*	*	*	28	Hammond 78
*	*	21	10	*	Hammond 84b
*	*	22	*	34	Krag & Webb (in press)
*	26	19	*	*	Krag *et al.* 86
*	16	30	*	*	Schwab & Watt 81
*	33	31	*	*	Schwab 78
*	59	31	*	*	Schwab 78(access logged)
*	17	29	*	*	Smith & Wass 76
*	*	*	*	61	Smith 86a
*	*	27	*	*	Thompson & Still 85
*	*	27	*	*	Thompson & Still 87
58	14	29	31	*	Cromack *et al.* 79
36	26	9	27	*	Dyrness 65
*	6	15	*	*	Garrison & Rummell 51
*	20	14	14	*	Hatchell *et al.* 70
*	*	*	*	19-26	McLeod & Hoffman 86
*	*	*	*	26	Steinbrenner & Gessel 55
*	13	16	*	*	Wooldridge 60

Table 5.1 (cont'd)

UNDIST	SL DIST	DEEP DIST	COMPACT	UNSP DIST	SOURCE
GROUND SKIDDING - WINTER (on snow and/or frozen ground)					
*	*	*	*	15	Cantlon 86
61	4	33	*	*	Carr & Mitchell 86
*	*	*	*	31	Hammond 78
*	27	14	*	*	Krag *et al.* 86
*	19	30	*	*	Schwab & Watt 81
52	31	21	*	*	Schwab 78
*	13	15	*	*	Smith & Wass 76
*	*	*	*	21	Smith 86a
SMALL CRAWLER TRACTOR - SUMMER					
*	*	18	*	*	Krag and Webb (in press)
SMALL CRAWLER TRACTOR - WINTER (on snow and/or frozen ground)					
*	*	*	*	17	Smith 86a
*	*	*	16	24	Watt & Krag 86
FELLER BUNCHER + GROUND SKIDDING					
*	*	*	*	22	Hammond 78
*	*	2	40	*	Laing & Howes 86
HIGHLEAD					
*	48	11	*	*	Bockheim *et al.* 75
*	7	*	*	*	Cantlon 86
*	*	9	*	*	Krag and Webb (in press)
*	14	12	*	*	Krag *et al.* 86
*	39	9	*	*	Schwab 78
*	12	9	*	*	Smith & Wass 76
57	22	10	9	*	Dyrness 65
*	*	*	*	16	Ruth 67

Table 5.1 (cont'd)

UNDIST	SL DIST	DEEP DIST	COMPACT	UNSP DIST	SOURCE
GRAPPLE					
*	11	15	*	*	Smith & Wass 76
JAMMER					
*	13	2	*	*	Garrison & Rummel 51
*	7	6	*	*	Smith & Wass 76
SKYLINE					
*	12	14	*	*	Schwab 76
*	8	0	*	*	Smith & Wass 76
*	*	*	*	8	Amaranthus & McNabb 83
73	9	24	27	*	Cromack *et al.* 79
64	24	5	3	*	Dyrness 67
*	*	*	*	6	Ruth 67
*	8	3	*	*	Wooldridge 60
BALLOON					
78	16	3	2	*	Dyrness 72
HELICOPTER					
*	33	3	*	*	Bockheim *et al.* 75
81	17	2	*	*	Clayton 81
HORSE					
*	10	2	*	*	Garrison & Rummel 51

landings. These areas are often scalped during construction, resulting in removal of surface organic layers and often surface soil horizons (Schwab 1978, Smith 1986a, Smith and Wass 1985b). Other soils are buried by sidecasts or fill materials. Repeated machine travel results in soil compaction, often to depths of 30 cm or more (Carr and Mitchell 1986, McLeod 1986a, Watt and Krag 1986).

In table 5.1, slight disturbance signifies displacement of the surface organic layers or shallow mixing with mineral soil, usually to a depth of less than 25 cm (a few authors have used a break of 5 cm). Deep disturbance signifies scalping of surface organic layers and removal of surface mineral horizons to a depth of greater than 25 cm, often including compaction and/or puddling. Compaction indicates a measured or otherwise observed increase in bulk density of significant proportion, usually greater than 20%. The areas of deep disturbance and compaction can generally be equated with soil degradation due to loss of nutrient capital and a decrease in porosity. Areas classed as slight disturbance are less likely to be degraded, with effects ranging from beneficial disturbance of shallow mixing, to detrimental scalping or compaction in some cases. Unspecified disturbance usually means exposed mineral soil, or areas occupied by roads and landings, which may include both slight disturbance and soil degradation. The actual impact of any type of disturbance will vary depending on the soil characteristics of a given site (see Chapter 6). The studies cited in table 5.1 are not strictly comparable due to variation in methods of area determination and definitions of disturbance, but they do summarize the results of investigations to date.

The studies cited in table 5.1 illustrate that the type of harvesting system employed can influence the degree of disturbance and degradation. The largest disturbances are clearly associated with summer skidder/crawler tractor operations. The impacts of ground-based systems tend to be reduced with light flotation or small tractors, by logging only when soils are dry or frozen, or on a firm snowpack, and by pre-planning skidroad networks (see also section 8.2.3). Highlead and other cable systems are able to keep disturbance levels to a minimum due to the lack of skidroads, however area occupied by main roads and landings is sometimes increased (Wellburn 1975, Krag *et al.* 1986). Yarding with balloons, helicopters, and horses creates the least disturbance.

Roads have also been shown to intercept subsurface seepage. This increases runoff and may degrade the soils downslope by reducing soil moisture levels during the growing season (Megahan 1986, Smith and Wass 1980). A study on the Idaho batholith demonstrated that subsurface flow intercepted by a roadcut could account for over 30% of streamflow under snowmelt conditions (Megahan 1972). These diversions also have potential impacts on erosion and sedimentation (Swanston and Swanson 1976).

The percent of logged areas affected by various yarding methods seems to be similar whether the harvesting system is clearcutting or selection (Cromack *et al.* 1979, Froehlich 1976).

5.2.2 Mechanical site preparation

The primary objectives of mechanical site preparation include fire hazard abatement, improved planting access, and the creation of environments which enhance seed germination and seedling survival (Ballard 1986, Dyck 1976). In practice this usually means reducing slash loading, controlling competing vegetation and removal or reduction of surface organic layers. Whether directly or indirectly, all of these practices reduce organic matter content of the soil, which in turn reduces nutrient retention and often detrimentally affects soil physical properties. The use of heavy machinery for site preparation may often lead to compaction and the possibility of erosion (Haines *et al.* 1975). However, the site specific effects of mechanical site preparation are highly variable, depending on site characteristics, site preparation method, season of treatment and operator ability.

Of the site preparation treatments commonly used in B.C., windrowing is the one with most obvious detrimental effects (Revel 1976). Repeated machine travel and pushing of slash with a front-mounted blade results in extensive scalping and compaction. Slash, surface organic layers, surface soil horizons, and ultimately a substantial portion of the site nutrients are concentrated into windrows covering a small percentage of the treatment area (Ballard 1977, Pye and Vitousek 1985). Bunching, blade scarification and V-blading have similar types of impacts, but often affect a smaller percentage of the treatment area (Herring and McMinn 1980). When the piles or windrows are burned, nutrient and organic matter losses due to combustion and volatilization are increased due to the concentration of fuels and increased intensity of the fire.

Windrowing is sometimes combined with stumping and rootraking for the control of root diseases. These treatments can result in 100% mineral soil exposure, mixing of infertile subsoils and significant compaction (Smith and Wass 1983b).

In contrast, drag scarification has less impact due to the absence of widespread scalping and the lack of repeated machine travel over single areas (Thompson 1978). Table 5.2 illustrates

Table 5.2: Percent of treatment area by site preparation method and disturbance class (Utzig and Still 1979).

TREATMENT([1])	UNDIST	SCALP	BURIED	MIXED	WINDROW
WINDROW(4)	10	41	10	25	14
BUNCH & BURN(1)	22	15	23	40	*
DRAG SCARIFY(2)	44	7	12	37	*

[1] Number of treatment areas sampled.

the variation in impacts, depending on the method of site preparation utilized. The study did not consider the effects of compaction.

The use of various tilling devices and plows may in fact ameliorate some compaction problems, and generally has a more beneficial mixing rather than scalping effect (Coates and Haeussler 1984, McMinn 1974). Patch scarifiers reduce the size and continuity of scalped areas. As suggested by Ballard (1986), small dispersed scalps are not likely to impair seedling nutrition as tree rooting extends into non-scalped areas.

However, the use of heavy machinery on wet, medium to fine textured soils always increases the risk of compaction. Also, mixing may be detrimental to the availability of some nutrients when deeper soil horizons of distinctly differing acidity or chemical characteristics are mixed with nutrient-rich surface horizons. Soil compaction, scalping and mixing have also been shown to affect the distribution and abundance of mycorrhiza-forming fungi and other soil organisms (Ballard 1986, Perry and Rose 1980).

As stated above, the potential for soil degradation by any one of these mechanical treatments will vary depending on a number of factors: the type of machine used, operator skill, slope, slash loading, depth of organic layers, nutrient distribution within an ecosystem, soil texture and coarse fragment content, soil moisture and temperature levels at the time of treatment.

5.2.3 Prescribed burning

The effects of slashburning have been the subject of extensive studies throughout the Pacific Northwest and B.C. and there has been conflicting opinion as to the overall long-term effect of burning (Feller 1982, McNabb 1986, Vihnanek 1985). There is clear evidence that slashburning can result in losses of a substantial portion of various soil nutrients, including nitrogen, phosphorus and potassium, through volatilization, wind erosion and/or waterborne surface erosion. Nutrients which are converted to a soluble state can also be lost by leaching when nutrient uptake is reduced due to destruction of vegetative cover. To what extent these losses occur and whether they are significant depends on many factors. These include the intensity and duration of the burn, soil moisture content at the time of burning, characteristics of surface organic horizons, organic matter content of the mineral soil, and the overall nutrient budget of the site in question (i.e. depth and texture of soil, nutrient and organic matter inputs over the rotation, leaching losses, etc.). Shallow, well drained organic soils (folisols) and other sites with significant portions of their nutrient capital located in standing biomass and surface soil horizons are most susceptible to the adverse effects of broadcast burning. These sites may in fact suffer long-term soil degradation due to broadcast burning (Feller 1982).

Broadcast burning usually results in a temporary increase in surface soil pH, which may be beneficial in some environments. However, on calcareous soils, and for some species, it can result in a decrease in nutrient availability. On calcareous soils in dry climates the effects can be long-lasting.

The effects of slashburning on soil biology are also hard to generalize. As mentioned above, with regard to nutrients the effects are quite variable depending on specific site conditions and the intensity of the burn itself. In some cases burning has been found to be a useful means of controlling detrimental organisms, however there is also a general reduction in the populations of beneficial organisms. To what extent these changes affect long-term soil productivity is poorly understood (Feller 1982, Perry and Rose 1980).

Broadcast burning is generally accompanied by the construction of perimeter fire-guards. These areas are generally scalped and/or gouged to mineral soil, and can be compacted, although probably not to the extent of road surfaces. However, because fire-guards follow the treatment area boundaries, they are often steep, and susceptible to soil erosion. One study has shown them to occupy three to five percent of the harvested area (Cantlon 1986).

5.2.4 Vegetation removal

Large-scale biomass removal through forest harvesting or vegetation management is another potential source of soil degradation, through direct removal of site nutrient capital and organic matter and temporary interruption of nutrient cycling. In the case of forest harvesting, nutrients are removed in the harvested material (Gessel *et al.* 1972, Weetman and Webber 1972). Other studies have reported increased leaching losses of nutrients following clearcutting and/or herbicide treatments (Bormann *et al.* 1968, Perry and Rose 1980). These are generally the result of increased decomposition rates and decreased nutrient uptake due to the absence of vegetation. In the majority of cases, it is felt that these losses *alone* are not significant to long-term productivity, as they are replaced by natural inputs over the rotation (Feller 1982, Stark 1979, Weetman and Webber 1972). As with nutrient losses associated with slashburning, sites with low nutrient capitals and low inputs are more susceptible to problems, particularly with full-tree harvesting (Carlisle and Chatarpaul 1984, Standish *et al.* in press). Changes in soil moisture regime due to clearcutting or vegetation removal may increase surface erosion and mass wasting (see section 5.2.6).

5.2.5 Pesticide applications

The use of pesticides (insecticides and herbicides) has increased in recent years and may have potential for long-term soil degradation. At present there are few studies looking at the long-term effects of pesticides or pesticide residues on the health of forest soils. The effects of insecticides and herbicides on soil organisms important for organic matter decomposition and soil nutrient cycling and availability are poorly understood, even though it is known that some pesticides can reduce or change the species mixes of soil organisms (Brady 1974).

The widespread use of herbicides may have implications for nutrient and organic matter content of forest soils because of the reduction in biomass production and interruption in nutrient cycling. Target and non-target brush species destroyed by herbicide treatments may include nitrogen fixers which play an important role in the nutrient budgets of some sites (Perry and Rose 1980).

5.2.6 Erosion

Erosion is a natural process which degrades soils constantly, especially in steeper terrain typical of much of the forest land in B.C. Soil erosion, which includes mass wasting, waterborne surface erosion, wind erosion and dry ravel, degrades the soil through removal of surface organic layers and mineral horizons. Studies have shown that forest management practices can increase the rate of soil erosion by two to fifteen times, thereby producing large areas of degraded soils (Froehlich 1978a, Klock 1982, O'Loughlin 1972, Schwab 1983). Road construction has been shown to be the forest management practice which has the greatest influence on soil erosion, but timber harvesting, site preparation, broadcast burning, and vegetation removal per se have also been shown to increase the rate of erosion (Gray and Megahan 1981, Packer and Williams 1976).

Road construction, timber harvesting and site preparation increase erosion primarily through the effects of soil exposure, drainage diversion, soil displacement, and compaction which reduces infiltration rates. Timber harvesting, site preparation, vegetation management and slashburning can change soil water regimes and affect soil strength by reducing vegetative cover and root strength (Gray and Megahan 1981). Slashburning can increase runoff by creating water-repellent layers in the soil (Feller 1982).

5.2.7 Interactions

When various site treatments are used in combination, the effects can be quite different and much more difficult to predict, than when treatments are applied individually. For example, a study in the southeastern U.S. showed that soil loss due to erosion was not increased significantly by herbicide applications alone. Whereas, windrowing and disking increased erosion by an order of magnitude (+/-10 times). However, when herbicide application was combined with windrowing and disking, soil loss due to erosion more than doubled over values for windrowing and disking alone. The erosion soil losses were however, an order of magnitude less than the losses due to scalping during windrowing (Pye and Vitousek 1985).

5.3 EXTENT OF SOIL DEGRADATION FROM FORESTRY PRACTICES

The area estimates of degraded soils arising from the application of forestry practices are restricted to lands treated during the ten-year period January 1976 to March 1986. The harvesting information includes Timber Supply Areas (TSA), Tree Farm Licenses (TFL) and Tree Farms (TF), while the silvicultural information only includes TSA's. The principal source of data was the B.C. Ministry of Forests and Lands Annual Reports (MOFLAR) for 1976 through 1985/86. Additional data regarding areas treated by the various harvesting systems and site preparation techniques was supplied by the Valuation, Silviculture and Protection Branches of the MOFL.

The data regarding slope classes and areas treated by specific harvesting systems and site preparation techniques is very limited and sometimes contradictory (for example, the area treated by a given practice in a specific year from one source could be 2 or 3 times that given by another source). An assumption was made to accept the MOFLAR's as presented, and other data was accepted, rejected or adjusted within that framework. Due to the general lack of information on the application of various harvesting systems and silvicultural treatments prior to 1976, it was felt that making estimates for years prior to 1976 was of questionable value. Some may argue that the data base is inadequate for the estimates presented; however, the same data base is considered adequate for annual allowable cut calculations. The authors argue that it is a useful exercise to make a first approximation of the extent of soil degradation, even if it is only a minimum. It also serves to identify where the deficiencies in the data base occur.

Sections 5.3.1 to 5.3.6 explain the assumptions inherent in the estimates of areas degraded by each forestry practice, and section 5.3.7 presents summary tables for the province as a whole. The authors have taken what they consider to be a conservative approach to the problem, based on presently available data. The estimates calculated in this Chapter are a first approximation of total area degraded, while the increased estimates presented in Appendix II, based on more liberal assumptions, may be more representative of the actual area degraded.

5.3.1 Mechanized harvesting operations

Total area logged was taken from the MOFLAR, 1976-1985/86 (see table 5.4). These areas include both clearcuts and selection logging, as the impacts of compaction and severe disturbance have been shown to be relatively similar. Table 5.3 presents the percentages of the area which were logged by various systems. These were based on data supplied by the Valuation and Silviculture Branches of MOFL. The percent of area degraded by each treatment (table 5.5) are estimates based on measured levels recorded in the literature cited in section 5.2. Considering that recent B.C. studies have shown that ground skidding can result in severe disturbance (assumed to be equivalent to soil degradation) of between 19 and 58% in the summer, and between 14 and 33% in the winter, the values chosen are conservative. This does not include areas of permanent haul roads, as they are presumed to be removals from the productive land base (this may not apply to all TSA's).

Even though the potential for soil degradation from ground-based yarding generally increases with increasing slope due to the need for skidroad construction, there is potential for significant degradation on slopes less than 35% from compaction and gouging in areas of complex terrain. Due to the lack of specificity in the data used to prepare Table 5.5, it is not possible to discretely define winter harvesting in regard to ground

Table 5.3: Percentage of total area harvested 1976-1985/86 by various harvesting systems* on specified slope classes (based on data from MOFL Valuation and Silviculture Branches).

FOREST REGION	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%	TOTAL
VANC CST	1	39	37	17	0.5	0	0	0	0	5	0.5	0	100
P RUP CST	0	21	35	4	2	0	0	0	0	35	3	0	100
VANC INT	0	20	19	10	0.5	0	24	2	0	22	2	0.5	100
P RUP INT	0	0	0	0	0	0	51	2	0.5	44	2	0.5	100
PR GEORGE	0	0	0.5	0.5	0.5	0	51	1	0.5	44	1.5	0.5	100
CARIBOO	0	0	0.5	0.5	0.5	0	50	2	0.5	43	2	1	100
KAMLOOPS	0	0	1	3	0.5	0	46	3	0.5	42	3	1	100
NELSON	0	0	1	4	2	0.5	35	12	3.5	31	9	2	100

Table 5.4: Total area harvested (ha) 1976-1985/86 by various harvesting systems* on specified slope classes (derived from MOFLAR's and table 5.3).

FOREST REGION	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%	TOTAL
VANC CST	3133	122205	115938	53269	1567	0	0	0	0	15667	1567	0	313347
P RUP CST	0	9984	16641	1902	951	0	0	0	0	16641	1426	0	47545
VANC INT	0	2421	2300	1210	61	0	2905	242	0	2663	242	61	12104
P RUP INT	0	0	0	0	0	0	95012	3726	931	81972	3726	931	186299
PR GEORGE	0	0	2587	2587	2587	0	263859	5174	2587	227643	7761	2587	517371
CARIBOO	0	0	1521	1521	1521	0	152132	6085	1521	130833	6085	3043	304263
KAMLOOPS	0	0	2777	8331	1388	0	127737	8331	1388	116629	8331	2777	277689
NELSON	0	0	2096	8383	4192	1048	73351	25149	7335	64968	18862	4192	209575
TOTAL	3133	134611	143860	77203	12266	1048	714996	48707	13763	657017	47999	13590	1868193

Table 5.5: Percentage of harvested area degraded by various harvesting systems* on specified slope classes (assumptions by the authors based on available literature).

	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%
COMPACT & DEEP DIST	3	10	10	10	15	17	15	17	20	22	25	25
ERODED	0.5	0.1	0.5	1.0	0.1	0.5	0.1	0.5	1.5	0.2	1.0	2.5
TOTAL DEGRADED	3.5	10.1	10.5	11	15.1	17.5	15.1	17.5	21.5	22.2	26	27.5

*HELI=helicopter, CABLE=cable yarding, LT FLOT=light flotation, GR=ground skidding, WIN=winter, SUM=summer.

conditions. Winter harvesting is assumed to have taken place on a firm snowpack and/or frozen ground.

5.3.2 Mechanical site preparation

The area treated by the various methods was taken primarily from the MOFLAR, 1976-1985/86 (see table 5.6). Additional data were supplied by the Silviculture and Protection Branches, MOFL. Estimates of degraded areas, as a percentage of area treated, are presented in table 5.7. The factors used were 40%, 30% and 20% for windrowing, bunching and blade scarification respectively. Many of these sites have additional degraded areas as a result of harvesting practices (e.g. a site on 35-50% slope which was ground skidded, windrowed and eroded could have 66% of the area degraded). There was concern expressed by all soil specialists contacted about the potential impacts of other types of mechanical site preparation equipment. For example, the assumption could be made that a percentage of all areas treated by mechanical site preparation are degraded due to compaction, or scalping in the case of some. However, due to a lack of studies on types other than blade scarification and windrowing, these areas were not included in the productivity loss calculations. In addition to the areas treated between 1976 and 1986, the windrowing study by Revel (1976) reports that an additional 27,600 ha were windrowed between 1971 and 1975, however these were not included.

5.3.3 Prescribed burning

Total area treated was taken from the MOFLAR, 1976-1985/86. Because the potential impacts of slashburning on soils are variable and not well understood (see section 5.2.3), only 10% of the total area broadcast burned is assumed to have been degraded by this practice (table 5.6). It was probably higher in areas treated prior to 1980, however burning and site diagnosis techniques have improved and the rate of degradation should be

Table 5.6: Total area (ha) treated by specified site preparation techniques 1976-1985/86 (based on MOFLAR's and data from MOFL Silviculture Branch).

FOREST REGION	BROADCAST BURN	WINDROW	BUNCH	BLADE SCARIFY	DRAG SCARIFY	OTHER MECH	CHEMICAL	TOTAL
VANCOUVER	36971	148	1149	697	5	775	24121	63866
PRINCE RUPERT	46763	1741	7344	4319	11294	12370	3953	87783
PRINCE GEORGE	101338	18689	43117	36660	65670	13595	8286	287354
CARIBOO	25030	371	18251	1313	6864	7800	0	59629
KAMLOOPS	30148	2847	34035	9629	7240	7064	10	90974
NELSON	15202	690	12785	9117	11631	2484	1192	53101
TOTAL	255452	24485	116682	61735	102704	44088	37561	642707

Table 5.7: Percentage of treated area degraded by specified site preparation techniques (assumptions by the authors based on available literature).

	BROADCAST BURN	WINDROW	BUNCH	BLADE SCARIFY	DRAG SCARIFY	OTHER MECH	CHEMICAL
% AREA DEGR	10	40	30	20	0	0	0

decreasing. This percentage includes not only degradation due to broadcast burning directly, but also associated fire guards. No areas have been included for degradation from spot burning.

5.3.4 Vegetation removal

The total area impacted by major biomass removal is equivalent to all areas clearcut, as stated in the MOFLAR, 1976-1985/86. These areas were not included in the calculation of productivity losses, as the presently available data does not indicate that nutrient losses from vegetation removal alone are sufficient to cause soil degradation. Vegetation removal areas are considered to be slightly impacted. However on some sites this may not be the case, and vegetation removal undoubtedly contributes to increased erosion.

5.3.5 Pesticide applications

Total area treated was taken from the MOFLAR, 1976-1985/86. Because little information is presently available on the long-term effects of pesticides on forest soils, no areas were included in the productivity loss calculations.

5.3.6 Erosion

Forest areas affected by erosion are very difficult to estimate because of the localized nature of the problem. To get around this, two simple assumption are made: the majority of erosion caused by forestry practices is associated with road construction and that most erosion occurs on steep slopes. Therefore areas designated as degraded by erosion are estimated as a percentage of harvested areas on slopes and where road construction occurs. The percentages increase with increasing slope and increasing road impacts (see table 5.5). For example, areas where cable yarding has been used on slopes of 35-50% have been estimated to have 0.5% of the area degraded by erosion, while areas with slopes over 50% and summer ground skidded are estimated to have

2.5% of the area degraded by erosion. The values are conservative considering that studies indicate that unstable portions of clearcuts can have from 0.3% to 4.3% of the area affected by mass wasting alone (Froehlich 1978b, Schwab 1983, Utzig and Herring 1975). The percentages presented cover all types of erosion and no specific allowance has been made for erosion associated with roads outside harvested areas.

Windrowing can also contribute to significant increases in erosion, but the losses due to erosion are considered insignificant when compared to the site degradation caused by the scalping. Clearcutting, herbicide applications, and broadcast burning have also been shown to increase erosion, but their contributions are assumed to be significantly smaller than the impacts of road construction.

5.3.7 Estimate of total extent of forest soil degradation

Tables 5.8 to 5.11 present the total area estimates for soil degradation as a result of forestry practices and resulting erosion, by Forest Region, for the period 1976 to 1985/86. The total area of degraded soils is over 20% of the area harvested during that period. The tables indicate that ground skidding is the most significant practice in terms of the area of degraded forest soils. Even though soil erosion can have serious consequences to other resources, it has limited impact on the overall extent of degraded forest soils.

Table 5.12 is an estimate of areas degraded by forestry practices during the year of 1985/86. Assuming that present forestry practices continue, the values in table 5.12 are an indication of the annual increase in the area of soil degradation. If this trend continues, by the year 2000, the degraded area may exceed one million hectares.

Table 5.8: Estimate of total area (ha) of degraded soils resulting from forest harvesting*
during 1976-1985/86 (derived from tables 5.4 and 5.5).

FOREST REGION	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%	TOTAL
VANC CST	94	12221	11594	5327	235	0	0	0	0	3447	392	0	33309
P RUP CST	0	998	1664	190	143	0	0	0	0	3661	357	0	7013
VANC INT	0	242	230	121	9	0	436	41	0	586	61	15	1741
P RUP INT	0	0	0	0	0	0	14252	633	186	18034	931	233	34270
PR GEORGE	0	0	259	259	388	0	39579	880	517	50082	1940	647	94550
CARIBOO	0	0	152	152	228	0	22820	1034	304	28783	1521	761	55756
KAMLOOPS	0	0	278	833	208	0	19161	1416	278	25658	2083	694	50609
NELSON	0	0	210	838	629	178	11003	4275	1467	14293	4715	1048	38656
TOTAL	94	13461	14386	7720	1840	178	107249	8280	2753	144544	12000	3397	315903

Table 5.9: Estimate of total area (ha) of degraded soils resulting from increased soil erosion associated
with forest harvesting* during 1976-1985/86 (derived from tables 5.4 and 5.5).

FOREST REGION	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%	TOTAL
VANC CST	16	122	580	533	2	0	0	0	0	31	16	0	1299
P RUP CST	0	10	83	19	1	0	0	0	0	33	14	0	161
VANC INT	0	2	11	12	0	0	3	1	0	5	2	2	39
P RUP INT	0	0	0	0	0	0	95	19	14	164	37	23	352
PR GEORGE	0	0	13	26	3	0	264	26	39	455	78	65	967
CARIBOO	0	0	8	15	2	0	152	30	23	262	61	76	628
KAMLOOPS	0	0	14	83	1	0	128	42	21	233	83	69	675
NELSON	0	0	10	84	4	5	73	126	110	130	189	105	836
TOTAL	16	135	719	772	12	5	715	244	206	1314	480	340	4958

Table 5.10: Estimate of total area (ha) of degraded soils resulting from specified
silvicultural practices during 1976-1985/86 (derived from tables 5.6 and 5.7).

FOREST REGION	BROADCAST BURN	WINDROW	BUNCH	BLADE SCARIFY	DRAG SCARIFY	OTHER MECH	CHEMICAL	TOTAL
VANCOUVER	3697	59	345	139	0	0	0	4240
PRINCE RUPERT	4676	696	2203	864	0	0	0	8439
PRINCE GEORGE	10134	7476	12935	7332	0	0	0	37876
CARIBOO	2503	148	5475	263	0	0	0	8389
KAMLOOPS	3015	1139	10211	1926	0	0	0	16290
NELSON	1520	276	3835	1823	0	0	0	7455
TOTAL	25545	9794	35005	12347	0	0	0	82691

*HELI=helicopter, CABLE=cable yarding, LT FLOT=light flotation, GR=ground skidding, WIN=winter, SUM=summer.

Table 5.11: Estimate of total area (ha) of degraded soils resulting from all forestry practices during 1976-1985/86 (derived from tables 5.8, 5.9 and 5.10).

FOREST REGION	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	TOTAL DEGR AREA (ha)	HARVESTED AREA (ha)
	(ha)							
VANC CST	33309	1299	3697	59	345	139	38848	313347
P RUP CST	7013	161	*	*	*	*	7174	47545
VANC INT	1741	39	*	*	*	*	1780	12104
P RUP INT	34270	352	4676	696	2203	864	43061	186299
PR GEORGE	94550	967	10134	7476	12935	7332	133394	517371
CARIBOO	55756	628	2503	148	5475	263	64774	304263
KAMLOOPS	50609	675	3015	1139	10211	1926	67574	277689
NELSON	38656	836	1520	276	3835	1823	46947	209575
TOTAL	315903	4958	25545	9794	35005	12347	403551	1868193

Table 5.12: Estimate of total area (ha) of degraded soils resulting from all forestry practices during 1985/86 (derived from MOFLAR and tables 5.3, 5.5 and 5.7).

	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	TOTAL DEGR AREA (ha)	HARVESTED AREA (ha)
	(ha)							
VANC CST	4371	170	366	10	5	4	4926	41118
P RUP CST	129	3	*	*	*	*	132	877
VANC INT	311	7	*	*	*	*	318	2164
P RUP INT	3871	40	869	527	278	35	5621	21044
PR GEORGE	10447	107	2350	2346	1275	756	17280	57163
CARIBOO	7633	86	164	93	237	1	8214	41652
KAMLOOPS	6100	81	273	85	525	259	7324	33473
NELSON	4196	91	242	132	644	105	5411	22750
TOTAL	37058	585	4264	3193	2965	1161	49226	220241

6.0 POTENTIAL LOSS OF CONIFER PRODUCTIVITY CAUSED BY SOIL DEGRADATION

6.1 INTRODUCTION

An area estimate of degraded soils created by forest management practices was generated in section 5.3. In this chapter the various categories of degraded soils will be examined as to their potential impacts on forest productivity. These potential reductions in growth will then be applied to the area estimates and normal growth rates to make an estimate of potential volume losses (section 6.3), their impact on the annual allowable cut (AAC, section 6.4), and the provincial economy (section 6.5).

The determination of actual or potential productivity losses due to soil degradation is a complex problem. Observed changes in productivity following various forestry practices are usually the result of an interaction of changes in many forest site variables, of which soil is only one (McNabb and Campbell 1985, Ballard 1986). All productivity studies reviewed by the authors have looked at changes in productivity where a variety of site factors have been altered by the treatments, not just soil. For example skidroad construction can modify soil properties (e.g. scalping and compaction), but it also causes changes in microclimate, vegetation competition and light availability. A change in any single factor may have a positive or negative influence on productivity. The observed or measured change in growth, however, is the net result of all the changes combined.

For example, studies by Ballard (1984, 1985) showed that white spruce growth was increased by slashburning and decreased by scalping during windrowing four to eight years after treatment. However, based on foliar analyses, the slashburning and windrowing resulted in the reduction of the nutrient (N, Cu and Fe) of the trees. He attributes these deficiencies to scalping, volatilization losses of nitrogen, pH effects on the solubility

solubility of Fe and Cu, and changes in micro-organism activity. The enhancement of growth on the slashburned site is attributed to improved soil temperatures which more than offset the nutrient losses. On the windrowed sites the complete removal of surface organic layers has not resulted in similar compensatory effects, and the net result is decreased productivity. It could be argued that there has been soil degradation on both sites, even though one has shown a positive growth response to the treatment.

For areas demonstrating a negative growth response to a treatment, for example blade scarification as reported by Herring and McMinn (1980), the net result of the various site changes is negative. Assuming that the effects of reduced competition and microclimate were positive, the actual decrease in productivity caused by reduced soil nutrition and organic matter content through scalping, was even larger than the measured net decrease.

The same type of treatment or disturbance may also have quite different regeneration results due to variation in soil properties (i.e. some soils are more susceptible to specific types of damage). For example, scalping or gouging coarse textured soils or soils with calcareous horizons at a shallow depth will probably have much more severe impacts on productivity than the same treatment applied to a fine textured soil with organic matter well incorporated into the mineral soil horizons.

Another consideration is the age of productivity measurements, relative to the rotation age. The positive effects of microclimate changes and reduced competition are often transitory, while some soil degradation effects can be of long duration or not manifest themselves until later in the rotation. Several authors have suggested that the initial gains in productivity from a variety of site preparation treatments may be reduced to little or even negative effects at rotation age

(Ballard 1986, Haines *et al.* 1975, McNabb and Campbell 1985). For example, nitrogen losses following slashburning are often thought to be insignificant, as there is often a positive growth response (Ballard 1986, Feller 1982, Vihnanek 1985). However the potential effect on growth may not be obvious until the demand exceeds the supply, for example at crown closure. It may even be a long-term problem which is not obvious until the second rotation (McNabb 1985).

There is also the potential for natural recovery of degraded soils due to revegetation and organic matter incorporation, nitrogen fixation, weathering and a decrease in compaction through formation of soil structure. The rate at which these processes operate varies considerably from site to site, and some studies indicate that the recovery can take decades (Froehlich *et al.* 1983, Herring and McMinn 1980). In contrast to productivity gains from silvicultural treatments which may be short-lived, productivity reductions due to soil degradation can be long-term, at least on some sites.

It is clear that there is an overwhelming lack of long-term studies to adequately define the potential effects of forestry practices on soil degradation and potential productivity losses. Because soil degradation effects on productivity may not be fully realized until later years in the rotation, and the losses presented here are mainly based on short-term studies, our estimates of losses are probably a minimum.

6.2 FOREST PRODUCTIVITY LOSSES ASSOCIATED WITH SOIL DEGRADATION

6.2.1 Mechanized harvesting

Soil compaction, soil displacement and scalping resulting from forest harvesting have been linked to decreased stocking levels, poor survival and initial growth of seedlings, and long-term reductions in growth of conifers. Table 6.1 summarizes the results from various studies. The values for height, diameter and volume are presented on an individual *tree* basis. The percentage growth changes compare the mean values for trees on disturbed areas with those in undisturbed areas. The *impact area* column reports differences between impacted and non-impacted parts of a treatment area, on a per hectare basis. This reflects not only differences in growth rate, but also reduced stocking in the impacted areas. The values presented as *total area* indicate changes in yield on a treatment area basis. The impact and total area values are usually measured changes in volume, however some studies have prorated height-growth changes over the treated area. For example, looking at the data from Wert and Thomas (1981), a tractor logged clearcut resulted in about 25% of the area compacted due to skid trails. Thirty-two years after logging, the trees growing on the compacted areas had heights, diameters and volumes, 30%, 28%, and 55% less than trees in the non-compacted areas of the clearcut. Due to decreased growth and lower stocking levels, the skid trails had 74% less volume per hectare than the non-compacted areas. This resulted in an overall volume loss of 12% to the clearcut as a whole.

Table 6.1 indicates that soil displacement, scalping and compaction associated with harvesting often results in growth reductions and reduced stocking. Froehlich and McNabb (1983) have demonstrated that for some soils and species every 2% increase in soil density will result in a 1% decrease in height-growth. The percent reductions in volume growth due to compaction generally exceed the reductions in height growth by two to three times (Froehlich 1979c), even for individual tree measurements. These reductions can be long-lasting and significantly reduce yields at rotation age.

Table 6.1: Productivity changes due to forest harvesting practices.

		GROWTH CHANGE (%)						
DISTURBANCE[1]	SPECIES[2]	TREE			IMPACT AREA[3]	TOTAL AREA[3]	AREA	SOURCE
		HT	DIA	VOL				
comp/scalp landings	Pl	6	-46	*	*	*	*	Carr 85
sl comp/skidrd	F	4	-11	*	*	*	*	
hvy comp/skidrd	F	4	-16	*	*	*	*	Froehlich 79b
sl comp/skidrd	Py	17	-11	*	-26	*	*	
hvy comp/skidrd	Py	17	-11	*	-66	*	*	
comp/skidroad	Pl	10-13	0	0	0	*	*	
	Py	9-18	-5	-8	-20	*	*	Froehlich *et al.* 86
comp/skidroad	Pt	1	-49	*	*	*	*	Hatchell *et al.* 70
comp/skidroad	Py	*	-14	-9	-29	-69	*	Helms & Hipkin 86
comp/skidroad	Pr	30	*	*	*	-80	*	Jakobsen 83
comp/skidroad	Pt	5	-59	*	*	-95	*	Lockaby & Vidrine 84
comp/skidroad	Pt	26	-13	*	*	-53		Perry 64
	B	18	+115	*	*	*	+13	
skidroads	Se	18	+112	*	*	*	+22	Smith & Wass 79
	B	13	-51	*	*	*	-15	
	Se	13	-52	*	*	*	-11	
	F	11	-57	*	*	*	-14	
skidroads	Se	12	-35	*	*	*	-2	Smith & Wass 80
	Lw	13	-36	*	*	*	-4	
	F	14	+59	*	*	*	+4	
comp/skidroad	F	32	-30	-28	-55	-74	-12	Wert & Thomas 81
comp/skidroad	F	2	-42	*	*	*	*	Youngberg 59
comp/thinning	F	35	*	*	*	-26	-9	Froehlich 76
comp/thin	Hw	22	*	-16	*	*	*	Froehlich 79c
mod comp/thin	Py	64	*	-6	*	*	*	Froehlich 79a
hvy comp/thin	Py	64	*	-12	*	*	*	
mod comp/thin	F	5-15	*	-14	*	*	*	Froehlich & Breglund 76
hvy comp/thin	F	5-15	*	-30	*	*	*	(age=yrs since thin)
comp/thin	Pt	45	*	*	*	-43	*	Moehring & Rawls 70
comp/harvest	Py	5	-50	*	*	*	*	Cochran & Brock 85

[1] Comp=compaction, thin=thinning, sl=slight, mod=moderate, hvy=heavy

[2] B=*Abies lasiocarpa*, subalpine fir; F=*Pseudotsuga menziesii*, Douglas fir; Hw=*Tsuga heterophyla*, western hemlock; Lw=*Larix occidentalis*, western larch; Pl=*Pinus contorta*, lodgepole pine; Py=*Pinus ponderosa*, ponderosa pine; Se=*Picea engelmannii*, engelmann spruce; Pt=*Pinus taeda*, loblolly pine; Pr=*Pinus radiata*, radiata pine.

[3] Generally volume; in some cases height growth prorated by stocking and/or area affected

Some researchers have found increased stocking and/or growth of conifers associated with soil disturbance (Pfister 1969, Smith and Wass 1976, 1979). In the case of Smith and Wass the enhanced growth was found for both Engelmann spruce and subalpine fir, mainly on northerly aspects and coarse textured soils. The enhanced growth was attributed to improved soil temperature regimes and decreased competition. In other research areas of the same study, growth reductions were also recorded. Pfister (1969) found enhanced growth of white pine below narrow *outsloped* roads. He attributed the better growth to decreased competition and increased water availability in sidecast material. This effect may have been offset by reduced water availability further downslope. Insloped roads however, decrease water availability downslope by converting subsurface flow to runoff. Megahan (1986) suggests that there may be increased water availability on the upslope side of the road, and a potential for increased productivity in this zone as well. For the purposes of these estimates, no specific growth reductions have been made for productivity losses due to reduced water availability.

Greacen and Sands (1980), in an extensive review of the effects of compaction, found that in 142 studies between 1970 and 1977, 24 species of trees were found to have decreased growth due to compaction, one showed enhanced growth, and one no change. There may be some special instances where growth can be enhanced by compaction and severe disturbance, but the evidence seems to indicate that these are rare.

For the calculations in this report we have assumed that seemingly positive growth responses to severe soil disturbance are rare, and are potentially positive responses to simultaneous changes in other site factors, not severe soil disturbance. On sites with positive growth responses to a treatment where severe soil disturbance took place, the response could potentially have been even greater if soil degradation had not occurred, or the net response in the long-term could still be negative (see also section 6.1). Positive growth responses to soil disturbance have not been considered in the calculations.

With height and diameter reductions ranging up to 59%, the question has to be raised whether areas with degraded soils will produce any merchantable stems at the desired rotation age. With even-aged management, the occurrence of small diameter stems on 15-25% of the harvest area will not necessarily change the rotation age of the whole treatment area. Those small stems will be cut and left as unmerchantable waste. This in effect, may create a 100% loss in productivity from the degraded soil areas. In Prince George a procedure has been proposed to take this into account when estimating productivity losses. The procedure employs a 100% reduction factor for severely disturbed areas and 25% for moderately disturbed areas (McLeod 1986b).

Based on the results of the studies quoted in table 6.1, the authors have selected the factor of 50% volume reduction for calculation of productivity losses on degraded soil areas resulting from timber harvesting. When applied to a 25% roaded area for summer ground skidding, this results in a 12.5% productivity loss over the harvested area as a whole (see Appendix II for a less conservative approach).

6.2.2 Mechanical site preparation

The primary objective of most site preparation is to improve seedling survival and/or growth. Many short-term studies have shown site preparation can achieve that objective by increasing the availability of light, decreasing competition and raising soil temperatures (Dyck 1976). However, other studies have linked soil compaction and scalping resulting from mechanical site preparation to decreased stocking levels, poor survival and initial growth of seedlings, and long-term reductions in growth of conifers. Table 6.2 summarizes the results from various studies.

The site preparation treatment which has been found to create the most consistent reduction in growth is windrowing. Blade scarification can have similar impacts to windrowing, however they are more localized. There is little available information on the impacts of other mechanical site preparation techniques on soil properties or long-term productivity. Most soils specialists contacted about impacts of other site preparation equipment (e.g. plows, scarifiers, choppers, trenchers etc.) expressed concern about long-term soil effects, but no one knew of any documented studies in B.C. Based on the results of studies described in table 6.2, equipment with mixing action is less likely to create degradation than equipment with scalping action. More study is needed.

For the purposes of calculating soil impacts for this study, windrowed areas were estimated to have a 50% reduction in growth rate over 40% the treated area due to scalping and compaction. Bunched areas were assumed to have a 50% reduction over 30% of the treated area. Blade scarified areas were assigned a 50% reduction for 20% of the treated area. These assumptions result in 20%, 15% and 10% reductions in productivity respectively, to the treatment areas as a whole. Other mechanical site preparation techniques were not assigned a reduction factor (see table 6.4).

6.2.3 Prescribed burning

The short-term negative impacts of broadcast burning are most likely to occur on sites with shallow duff layers and shallow or coarse textured soils; however, there are potential growth losses on other sites as well if long-term nutrient deficiencies occur. The growth reduction factor of 50% will be applied to the area

Table 6.2: Productivity changes due to silvicultural practices.

DISTURBANCE[1]	SPEC[2]	AGE	GROWTH CHANGE (%) TREE HT	GROWTH CHANGE (%) TREE DIA	GROWTH CHANGE (%) TREE VOL	GROWTH CHANGE (%) IMPACT AREA[3]	GROWTH CHANGE (%) TOTAL AREA[3]	SOURCE
windrow	Pr	7	-5	+8	-19	-19		
2cm scalp/comp	Pr	7	-5	-61	-40	-40	-22	Ballard 77
26cm scalp/comp/ landing/ripped	Pr	7	-51	-61	-64	-65		
scalp/windrow	Sw	8	-30	*	*	*	*	Ballard 85
scalp/windrow	Pt	19	*	*	*	*	-46	Haines *et al.* 75
scalp/blade scar	Bl	21	-80	*	*	*	*	
scalp/blade scar	Se	21	-80	*	*	*	*	Herring & McMinn 80
mixing	Pl	2	+82	*	*	*	*	
vegetation clip	Pl	2	+27	*	*	*	*	
scalp/blade scar	Pl	2	+18	*	*	*	*	
mixing	Sw	2	-71	*	*	*	*	McMinn 74
vegetation clip	Sw	2	+28	*	*	*	*	
scalp/blade scar	Sw	2	-14	*	*	*	*	
broadcast burn	F	5	*	*	-2	*	*	
pile & burn	F	5	*	*	-26	*	*	Minore 86
hvy comp/scalp/	F	2	-35	*	*	*	*	
stumping	F	2	+5	*	*	*	*	
to control	Pl	2	-15	*	*	*	*	Smith & Wass 83b
root disease	Lw	2	+40	*	*	*	*	

[1] Comp=compaction, scar=scarification, sl=slight, mod=moderate, hvy=heavy

[2] F=Pseudotsuga menziesii, Douglas fir; Lw=Larix occidentalis, western larch; Pl=Pinus contorta, lodgepole pine; Sw=Picea glauca, white spruce; Pt=Pinus taeda, loblolly pine; Pr=Pinus radiata, radiata pine.

[3] Generally volume; in some cases height growth prorated by stocking and/or area affected.

Table 6.3: Productivity changes due to erosion.

DISTURBANCE	SPEC[1]	AGE	GROWTH CHANGE (%) TREE HT	GROWTH CHANGE (%) TREE DIA	GROWTH CHANGE (%) TREE VOL	GROWTH CHANGE (%) IMPACT AREA[2]	GROWTH CHANGE (%) TOTAL AREA[2]	SOURCE
landslide area	F	5-18	-62	*	*	-75	*	Miles *et al.* 84
3cm scalp	F,Py	<1	*	*	-85	*	*	Klock 82
soil-bioassay	Pl	<1	*	*	-25	*	*	(vol=dry weight)
surface erosion remove A horizn	Pt	21	-50	-50	*	*	*	Maki *et al.* 62
landslide area	Cw,Cy Hw,Ss	30-59	*	*	*	-70	*	Smith *et al.* 86

[1] Cw=Thuja plicata, western red cedar; Cy=Chamaecyparis nootkatensis, yellow cedar; F=Pseudotsuga menziesii, Douglas fir; Hw=Tsuga heterophyla, western hemlock; Pl=Pinus contorta, lodgepole pine; Py=Pinus ponderosa, ponderosa pine; Ss=Picea sitchensis, sitka spruce; Pt=Pinus taeda, loblolly pine.

[2] Generally volume; in some cases height growth prorated by stocking and/or area affected.

impacted (10% of the broadcast burned area). This results in a 5% reduction overall (see table 6.4).

6.2.4 Erosion

Severely eroded areas, such as headscarps and gullies, often remain unstocked for most of the rotation. All eroded areas have significant seedling establishment delays, as well as decreased growth (see table 6.3). Due to even-aged management strategies and the need for stabilization of erosion surfaces, it is unlikely they will contribute to the next rotation. Therefore, for the purposes of these calculations, eroded areas have been designated to have a 100% reduction factor (see table 6.4).

6.2.5 Areas with minor or unknown growth impacts

As described in section 5.3, certain treatments such as clearcutting, use of some mechanical site preparation techniques and pesticide application have potentially damaging, but unconfirmed or mixed effects on soil productivity. For the purposes of the calculation of reduced growth, they will be noted as lightly or potentially impacted, but no growth reduction will be calculated. In the case of mechanical site preparation, slashburning and pesticides, further long-term studies are warranted.

6.3 POTENTIAL VOLUME LOSS ON A FOREST REGION BASIS

Utilizing the areas estimated in section 5.3, the growth factor reductions estimated in section 6.2, and mean annual increments (MAI) for the various forest regions, current annual growth losses on a forest region basis were calculated:

$$\underset{\text{AREA (ha)}}{\text{DEGRADED}} \quad \text{X} \quad \underset{(\text{m}^3/\text{ha/yr})}{\text{MAI}} \quad \text{X} \quad \underset{\text{REDUCTION}}{\text{PERCENT}} \quad = \quad \underset{(\text{m}^3/\text{yr})}{\text{GROWTH LOSS}}$$

The results are presented in table 6.5. Table 6.6 presents the estimated reductions in growth resulting from forestry practices for the single year of 1985/86. Tables 6.5 and 6.6 show that the

Table 6.4: Percentage reduction in growth applied to degraded areas of each degradation class (assumptions by the authors based on available literature).

	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR
% GROWTH REDUCTION	50	100	50	50	50	50

Table 6.5: Estimate of the current annual growth losses (m3/yr) occurring on degraded soils as a result of forestry practices during 1976-1985/86 (derived from tables 5.11, 6.4, and MOF 1980).

FOREST REGION	TOTAL DEGR AREA (ha)	MAI m3/ha/yr	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	TOTAL LOSS
			(m3/yr)						
VANC CST	38848	4.3	71614	5585	7949	127	741	300	86316
P RUP CST	7174	2.6	9117	418	*	*	*	*	9535
VANC INT	1780	2.8	2437	110	*	*	*	*	2547
P RUP INT	43061	1.5	25702	528	3507	522	1652	648	32560
PR GEORGE	133394	1.7	80367	1645	8614	6354	10995	6232	114207
CARIBOO	64774	1.4	39029	880	1752	104	3833	184	45781
KAMLOOPS	67574	2.0	50609	1350	3015	1139	10211	1926	68248
NELSON	46947	2.1	40589	1756	1596	290	4027	1915	50173
TOTAL	403551		319464	12271	26433	8536	31459	11204	409367

Table 6.6: Estimate of the current annual growth losses (m3/yr) occurring on degraded soils as a result of forestry practices during 1985/86 (derived from tables 5.12, 6.4, and MOF 1980).

FOREST REGION	TOTAL DEGR AREA (ha)	MAI m3/ha/yr	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	TOTAL LOSS
			(m3/yr)						
VANC CST	4926	4.3	9397	733	786	22	11	8	10957
P RUP CST	132	2.6	168	8	*	*	*	*	176
VANC INT	318	2.8	436	20	*	*	*	*	455
P RUP INT	5621	1.5	2903	60	652	395	209	26	4245
PR GEORGE	17280	1.7	8880	182	1997	1994	1084	642	14779
CARIBOO	8214	1.4	5343	120	115	65	166	1	5810
KAMLOOPS	7324	2.0	6100	163	273	85	525	259	7406
NELSON	5411	2.1	4406	191	255	139	676	111	5776
TOTAL	49226		37633	1475	4077	2700	2671	1048	49605

Province is presently loosing approximately 400,000 m^3 of forest growth annually due to soil degradation caused by forestry practices between 1976 and 1985/86. If present practices and harvesting rates continue, by 1990 the annual losses may reach 600,000 m^3, and by the year 2000 growth losses may exceed one million cubic metres per year.

It must be kept in mind that these are only estimates of the growth reductions resulting from soil degradation caused by forestry activities subsequent to 1976. They do not include current losses due to lands degraded prior to 1976. Considering that in the late 1960's high elevation burning was standard practice on the coast, and that over 27,500 hectares were windrowed between 1971 and 1975 alone (Revel 1976), there is certainly a substantial area in addition to that estimated here, even though the annual harvested area was somewhat smaller.

For simplicity, the percent reductions were applied to the mean MAI for the region as a whole (with a coast/interior break). This implies that the harvesting and site treatments were applied proportionately across the various site classes, and the growth losses are proportional on all site classes. However, silvicultural treatments are presumably applied primarily to good and medium sites, while low and poor sites are likely to suffer greater losses in yield due to problems of piece-size and even-age management. The estimates of silvicultural treatment areas do not include degraded areas generated on TFL's or TF's between 1976 and 1985/86, as this information was not readily available. Therefore total productivity losses on a provincial basis may be under-estimated.

6.4 IMPLICATIONS TO THE ANNUAL ALLOWABLE CUT (AAC)

There is no question that productivity losses due to soil degradation have a negative effect on the long-term sustainable yield. It will be a factor which amplifies the "fall-down effect". Unfortunately, there is insufficient data at present to determine the extent of the effect, particularly on a provincial scale. In addition, the problem is growing every year, as more roads are constructed, more areas harvested and more areas receive silvicultural treatments. The estimates made in section 6.3 serve to identify the order of magnitude of the problem, and point out which activities are contributing the major portion of the degradation.

When considering the effect on the AAC, the complexity increases one more step. Not only do environmental and forest management techniques change from region to region, so do approaches to reduction allowances in the AAC. Each Timber Supply Area (TSA) and Tree Farm License (TFL), reduces the long-term sustainable yield in consideration of environmental protection, anticipated land alienation, constraints imposed by other uses, and in some cases soil degradation from management practices. These reductions are TSA-TFL specific, and those dealing with soil degradation can range from 0 to 8%, but sometimes include losses due to other factors as well (e.g. permanent roads). Consideration of the potential impact of soil degradation on the AAC would require a detailed analysis of present allowances in every management unit, in addition to the determination of an appropriate reduction factor for each unit. This is beyond the scope of this problem analysis.

6.5 COSTS OF SOIL DEGRADATION

The most direct cost of soil degradation is reduced productivity. In the same sense that intensive management is justified as a way to make up for a dwindling land base, soil degradation is equivalent to reducing the land base even more. The methodology for predicting the long-term costs of soil degradation is parallel to that for predicting long-term returns on silvicultural investments.

Soil degradation has effects on both tangible and intangible values. Tangible values might be considered as lost stumpage whereas intangible might include the loss of jobs, off-site costs, and public image. In consideration of tangible values, in particular stumpage, one of the approaches to determining costs of soil degradation has been the net present value (NPV) analysis. The approach taken here is to determine a NPV of a degraded stand and a NPV for a similar stand that is not degraded. Presumably, the difference is the cost of degradation (in terms of today's dollar) with respect to foregone timber values resulting from reduced productivity. As pointed out by Carr (1985a) such calculations will be very sensitive to interest rates, assumed future stumpage and yield models (note that yield models for degraded sites probably don't exist for most of B.C.). In order to illustrate a net present value analysis, the following analysis is provided:

Location: Interior Cedar Hemlock
Assumptions for All Examples:

1. An average unmanaged stand yields $280 m^3$/ha at a rotation age of 100 years
2. No returns are received until logging (at 100 years)
3. Stumpage is expressed in real terms (present dollars) so no allowance for inflation is necessary.
4. Values other than stumpage are not significant.
5. Other forgone benefits or increased costs are not considered (eg. increased harvesting costs due to smaller piece size and reduced volumes per hectare or off-site damages).
6. $$NPV = \frac{FV}{(1 + i)^n}$$

where FV = future value
n = number of years to rotation
i = discount rate

Assumptions for Specific Examples

1. Tables 6.7 and 6.10 assume stumpage at rotation age will be 3 times historic high values; Table 6.8 and 6.9 assumes stumpage at 9 times historic high values.

2. Tables 6.7 and 6.8 and 6.10 assume a discount rate of 1%; Table 6.9 assumes a discount rate of 3%.

3. Tables 6.7, 6.8 and 6.9 assume a 50% reduction in productivity on the degraded area; Table 6.10 assumes a total reduction.

In regard to these analyses (Tables 6.7, 6.8, 6.9 and 6.10) it should be noted that the analysis is very sensitive to the discount rate chosen and assumptions made regarding future value (stumpage). The comparison of table 6.7 to 6.8 illustrates the sensitivity regarding future value, whereas the comparison of table 6.7 and 6.9 illustrates the sensitivity to discount rate.

The analysis is also very sensitive to the assumptions made regarding yield loss resulting from soil degradation. The comparison of table 6.7 to 6.10 illustrates this by assuming a 50% yield loss and 100% yield loss respectively. Some stands may become unmerchantable due to small piece size and low volumes per hectare (e.g. 140 m^3/ha in table 6.10).

The NPV of yield loss can be equated to the benefit derived from an investment made to avoid the loss. The value of the yield loss can be a justified expenditure for a treatment designed to avoid that loss. For example, as shown in table 6.7, if 20% of an area is degraded, $154/ha could be spent on a treatment to avoid the yield loss due to soil degradation. However, if 20% of the area is degraded and there is a 100% yield loss, then table 6.10 shows there is a potential treatment cost of $280/ha.

Given that rehabilitation costs are in the range of $500 to $5,000/ha, it would appear that such rehabilitation is not cost

TABLE 6.7 Net present value calculation with stumpage rates at 3 times historic values, discount rate of 1%, and 50% productivity reduction for degraded area.

Area Degraded %	Yield (m^3/ha)	Future Value of Yield ($/ha)	Net Present Value ($/ha)	Net Present Value of Yield Loss ($/ha)
0	280	$4,200	$1,552	n/a
10	266	$3,990	$1,475	$77
20	252	$3,780	$1,398	$154
30	238	$3,570	$1,320	$232
40	224	$3,360	$1,242	$310
50	210	$3,150	$1,165	$387

TABLE 6.8 Net present value calculation with stumpage rates at 9 times historic values, discount rate of 1%, and 50% productivity reduction for degraded area.

Area Degraded %	Yield (m^3/ha)	Future Value of Yield ($/ha)	Net Present Value ($/ha)	Net Present Value of Yield Loss ($/ha)
0	280	$12,600	$4,657	n/a
10	266	$11,970	$4,425	$ 231
20	252	$11,340	$4,194	$ 462
30	238	$10,710	$3,960	$ 696
40	224	$10,080	$3,726	$ 930
50	210	$ 9,450	$3,495	$1,161

TABLE 6.9 Net present value calculation with stumpage rates at 9 times historic values, discount rate of 3%, and 50% productivity reduction for degraded area.

Area Degraded %	Yield (m^3/ha)	Future Value of Yield ($/ha)	Net Present Value ($/ha)	Net Present Value of Yield Loss ($/ha)
0	280	$12,600	$656	n/a
10	266	$11,970	$623	$ 33
20	252	$11,340	$590	$ 66
30	238	$10,710	$557	$ 99
40	224	$10,080	$524	$132
50	210	$ 9,450	$492	$164

TABLE 6.10 Net present value calculation with stumpage rates at 3 times historic values, discount rate of 1%, and 100% productivity reduction for degraded area.

Area Degraded %	Yield (m^3/ha)	Future Value of Yield ($/ha)	Net Present Value ($/ha)	Net Present Value of Yield Loss ($/ha)
0	280	$4,200	$1,522	n/a
10	252	$3,780	$1,398	$124
20	224	$3,360	$1,242	$280
30	196	$2,940	$1,087	$435
40	168	$2,520	$ 932	$590
50	140	$2,100	$ 776	$746

justifiable (especially when success can not be guaranteed). Costs for the prevention or reduction of soil degradation by means of utilizing alternative harvesting systems are estimated at between $250 to $1,800/ha suggesting that some of these techniques may be cost justifiable. Pre-harvest planning can signficantly reduce soil degradation for costs ranging from a few dollars to $200/ha. Clearly, such methods of preventing or reducing soil degradation are cost justifiable. It is obviously preferable to improve planning and avoid soil degradation where possible, than to pay for rehabilitation which may have questionable success.

An alternative method of estimating the cost of reduced productivity resulting from soil degradation is to use a method commonly termed the Allowable Cut Effect (ACE). As explained by an economist:

> If, in the view of the Chief Forester, the potential loss in forest productivity is serious enough, he may have to adjust downward his estimates of Long Run Sustained Yield, and hence the annual allowable cut (AAC). A reduction in AAC leads to immediate loss of harvests, forest revenues, employment and related economic activity. If this translation can be made, then we have much more readily quantifiable consequences to deal with, and some of the serious problems associated with long-term forecasting and discounting can be partly avoided (Bowden 1986).

The ACE can only be used where there is a sufficiently even distribution of age classes to allow operational plans to respond to the AAC changes. Forest profiles in most of the Province's management units (TSA's and TFL's) allow use of the ACE.

At present, the AAC allowances for productivity losses due to soil degradation are variable from one management unit to another (see section 6.4). But, even if the presently committed AAC's already have a sufficient reduction factor, and would therefore require no adjustment downward to accommodate the estimated loss in productivity due to soil degradation, the reduction in AAC still represents a forgone benefit.

The Association of B.C. Professional Foresters (ABCPF 1985) has recently released a paper where they attempt to estimate the economic benefits arising from the harvesting of wood in B.C. Therefore as an example of the potential magnitude of the costs (or forgone benefits) of soil degradation, the values proposed by the ABCPF have been applied to the estimated loss in current annual increment due to soil degradation created between 1976 and 1985/86 (see table 6.5). The ABCPF has estimated that every cubic metre of wood harvested in B.C. creates direct economic benefits of $115 and indirect benefits of approximately $85, for a total of $200/m^3. Based on the estimate of lost productivity, the soil degradation created between 1976 and 1985/86 may be costing the provincial economy over $80 million annually (table 6.11). With the yearly accumulation of areas influenced by soil degradation, this number will double by 1995 (see table 6.6).

There are other costs which are not borne directly by the forest industry or the provincial stumpage account. These are costs related to the off-site impacts of erosion on other resources, and the unpredictable long-term costs of a degraded environment. On the coast, these costs have been the cause of considerable controvery in relation to the salmon fishery (Everest 1978). In the interior, the issues have focused on impacts on domestic and agricultural water supplies (Hammond 1986b). Site degradation can also have impacts on wildlife habitat and recreation values.

The costs of soil degradation have to be calculated in their entirety before there can be a true evaluation of the potential benefits of avoiding soil degradation or rehabilitating degraded soils (Klock 1976).

Table 6.11: Estimated annual economic losses due to soil degradation resulting from forestry practices between 1976 and 1985/86 (assuming $200/m³)

FOREST REGION	DEGRADED AREA (ha)	PRODUCTIVITY LOSS (m³/yr)	ANNUAL ECONOMIC ACTIVITY LOSS ($ million)
	-----(from table 6.5)------		
VANCOUVER	40628	88863	17.8
PR RUPERT	50235	42095	8.4
PR GEORGE	133394	114207	22.8
CARIBOO	64774	45781	9.2
KAMLOOPS	67574	68248	13.7
NELSON	46947	50173	10.0
TOTAL	403551	409367	81.9

7.0 SOIL DEGRADATION AS RELATED TO BACKLOG NOT-SATISFACTORILY RESTOCKED (NSR)

7.1 INTRODUCTION

This chapter briefly examines the notion that there is a link between existing NSR (Not Satisfactorily Restocked) land and soil degradation from two perspectives. First, to what extent is soil degradation responsible for the province's existing NSR land and second, are silvicultural methods currently being used to rehabilitate NSR sites resulting in the occurrence of soil degradation.

NSR is a term used by the Ministry of Forests and Lands to denote, on forest inventory maps, those portions of the land (map polygons) which do not have a satisfactory stocking of acceptable trees. Stocking relates to the number of trees per unit area. Backlog NSR is defined as follows (Boateng 1984):

> "Areas that are not satisfactorily restocked, and older than 3 years (Coast) or 5 years (Interior) or, have exceeded the prescribed silvicultural regeneration period for the area."

The reader is cautioned that this definition of NSR provided by Boateng (1984) is quite general. In fact, the definition of NSR can vary among MoFL Branches, Forest Regions, Districts and site classification schemes, to name a few. The authors understand that work is currently being undertaken by the MoFL to provide a more useful definition of NSR.

According to a recent FRDA publication (FRDA 1987), there are approximately 737,980 ha of NSR lands on good and medium sites in the Province which are not contributing to their potential forest growth.

7.2 SOIL DEGRADATION AS A FACTOR CONTRIBUTING TO NSR.

As discussed in Chapter 3, forest soil degradation has been defined as a term connoting loss of productivity resulting from changes in soil attributes. Even though significant, a loss in productivity does not necessarily result in an area being classified NSR.

However, studies have shown that soil degradation due to compaction and/or scalping can result in reduced stocking and poor seedling survival as well as reduced productivity (Carr 1985a, Helms and Hipkin 1986, Pomeroy 1949, Wert and Thomas 1981).

If well distributed throughout a treatment area, a soil degradation induced stocking reduction could result in an area being classified NSR. In many instances however, the effect of soil degradation is masked because it occurs as small or narrow parcels that are not adequately described by the presently used regeneration survey methods. For example, skidroads may be missed due to the use of widely spaced regeneration plots or in the case of severely disturbed areas ignored as unplantable spots.

In some extreme situations such as slope failures, extensive and severe disturbance due to harvesting or mechanical site preparation or slashburning on shallow soils, there is a direct relationship between soil degradation and NSR. There may also be a relationship between soil disturbance and NSR due to the invasion of the site by brush species benefiting from the exposure of mineral soil or the increased soil productivity.

At present there is no simple and reliable basis on which to evaluate the potential causal link between forest soil degradation and NSR. There are presently ongoing problem analyses of silvicultural practices in the Interior Cedar Hemlock zones of the southern interior which should further elucidate this problem. In general, the respondents to our questionnaire attributed NSR backlog primarily to inappropriate or inadequate silvicultural treatments, and felt soil degradation was only responsible in a limited way.

7.3 SOIL DEGRADATION AS A RESULT OF NSR REHABILITATION TREATMENTS

As reported in the Ministry of Forests and Lands Annual Report (1985/86), there were a total of 16,039 hectares of land improved by way of site rehabilitation during 1985/86. Site rehabilitation in this context includes:

- Brushing and Weeding
- Conifer Release
- Seed Tree Control
- Site Preparation
- Mistletoe Control
- Pruning
- Sanitation Spacing
- Slashing

Of these eight techniques used for site rehabilitation, the main ones which may be considered as potentially resulting in soil degradation are site preparation and brushing/weeding. Site preparation is a treatment to prepare a site for the favourable reception and satisfactory growth of either naturally or artificially disseminated crop tree seed or planted seedlings. Brushing/weeding is performed during the seedling stage of the crop trees, to control competing undesirable vegetation (Humphreys and Ackerman 1986).

The methods employed in site rehabilitation vary with site characteristics and perceived needs. For the most part, they entail either some mechanical site preparation, burning and/or elimination of competing vegetation (chemical or manual).

Mechanical site preparation techniques include the use of crawler tractors, low ground pressure tractors, mowing attachments, and cutters, discs, brushers and chains. Of this group, the crawler tractor equipped with a brush blade is considered to have the most potential for imparting soil degradation by means of soil compaction and disruption of surface organic layers.

Herbicides are often the favoured method for control of competing vegetation in B.C. due to their perceived cost effectiveness. Newton and Norris (1980) concluded that herbicides cause no physical impact on soils and do not result in loss of ecosystem productivity. However, Trappe *et al.* (1984) in reviewing herbicide effects on one group of soil micro-organisms pointed out the inconclusiveness of present understanding. He states:

> "About 90 papers, 60% of all published on the effects of pesticides on mycorrhizae, have appeared since 1976. How far have we progressed toward overcoming confusion and rationally explaining contradictory results? We are forced to conclude that progress has been disappointing; indeed, the case should be made that we have regressed, because the recent literature has added to the list of contradictory results without significantly improving our understanding of why most pesticides affect mycorrhizal fungi and mycorrhiza formation in the ways that they do. This regression might be expected to continue, because new pesticides are being added to the market faster than mycorrhiza researchers can deal with them."

Even though the goal of site rehabilitation is to promote the growth of commercial tree species, soil degradation may occur through some of the techniques used. At present, data and information are severely lacking in regard to measuring the potential impacts.

8.0 PREVENTION OF SOIL DEGRADATION

8.1 INTRODUCTION

It must be recognized that soil degradation cannot be completely eliminated. A certain amount of the land base is required for forest access and harvesting activities. There will always be impacts from whatever management treatments are applied. The objective of effective management is to keep those impacts to a minimum (Forest Engineering Research Institute of Canada 1983).

The most effective and least expensive means of minimizing soil degradation is careful planning of harvesting and silvicultural systems. Careful planning allows for the selection of alternate methods which may achieve the same management objectives, but with reduced soil degradation. In extreme cases, reduction of soil and site degradation may require a change of objectives to achieve acceptable levels.

The first step in any plan is an adequate resource inventory. To minimize soil degradation, this requires at least a minimum characterization of the soils, including texture, moisture regime, slope, depth, surface organic layers, and at least a generalized indication of nutrient status. From this information the soil can be assessed with regard to risk of various forms of degradation. For example, it can be assessed whether compaction is likely to occur and in what seasons.

The second step is to have a thorough understanding of what the impacts of the chosen management treatment are. For example: How many passes with this machine does it take to compact the soil? What area is likely to be disturbed with this logging system on these slopes? What is the cost of this machine in relation to one with a lower impact? Will this site preparation result in soil mixing or soil scalping? over what percent of the area? Impact assessments of a treatment have to be completed before a treatment is approved for widespread application.

With these two types of information in hand, a prediction of the impacts can be made, and a logical decision as to what method is best suited. Unfortunately this information is often not available, or at least is not in the hands of the decision maker.

Even with good plans, there is still need for careful supervision of the implementation phase. Machine operation is often an important factor in the degree of resulting degradation.

8.2 METHODS OF PREVENTION

8.2.1 Road construction

Since roads are a primary source of soil degradation, whether directly from their running surfaces or secondarily as the source of erosion, every attempt should be made to reduce their overall area. This can be accomplished through better planning of road systems and/or changing to harvesting systems which require fewer roads (Donnelly 1977, Peters 1978). Road location criteria can be used to avoid soils which are most susceptible to erosion. It is also possible to reduce the impacts of roads through the use of improved construction techniques and installation of adequate drainage systems. End-hauling and backfill shovel construction can reduce sidecasting (Bourgeois 1978, Schwab 1983).

8.2.2 Harvesting systems

As shown in table 5.1, ground skidding often produces two to three times more disturbance than cable systems. Balloon and helicopter logging have even less impact. An obvious means of reducing disturbance is to limit the use of ground skidding. This could reduce the occurrence of soil degradation by 50% to 60% in many areas.

8.2.3 Ground skidding

Because of the increased costs involved in switching from ground skidding to other harvesting systems, there has been substantial research into ways of reducing the impact of ground skidding. In *some* cases, with the use of special techniques, the area degraded by ground skidding can be reduced to levels similar to those of cable systems, with very little increase in cost. These will be outlined in the following paragraphs.

One technique is the use of light flotation or low ground-pressure equipment such as the FMC. Studies in Oregon have shown that use of this equipment can substantially reduce soil compaction on some soils (Froehlich 1978a). However on steeper slopes, the level of disturbance increases. A study in Ontario has shown reduced compaction resulting from the use of wide tires on a rubber-tired skidder (Schurman & MacKintosh 1985).

Another alternative is to use smaller equipment with a narrower track width, and hence reduce the width of skidroads. A recent study in the Cariboo has shown that these smaller machines can achieve disturbance levels nearly as low as cable systems under some conditions (Krag and Webb 1987).

Soil moisture level has a profound effect on trafficability and resistance to compaction (Greacen and Sands 1980). Restricting the use of heavy machinery to seasons when soil water content is low would greatly reduce compaction. Operating on frozen ground can also reduce compaction (McLeod 1986a).

As shown by table 5.1, ground skidding on snow can reduce the percent of the harvested area disturbed. Compaction is reduced and shallower cuts are required to construct skidroads on steep terrain. Harvesting disturbance between skidroads is also reduced with snow cover. Operating on snow requires planning and flexibility, especially in a year when less than expected snowfall occurs and harvesting has to be deferred until the following year.

A method which has been little used in B.C., but is extensively used in the U.S. Pacific Northwest, is pre-planned or designated skidroads. On steep ground, landings and skidroads are planned, laid out and constructed prior to logging, in order to take advantage of natural terrain features and limit soil disturbance and compaction to a predetermined percentage of the harvest area. On flat areas, landings and skidroads are designated and flagged on the ground prior to logging. Machines are not allowed to leave the constructed or designated trails and landings during the logging operation. By this method, the area affected by disturbance and compaction can be predetermined and controlled, occasionally with a reduction in costs to the operator. The results of various trials are presented in table 8.1. Even though this technique has been advocated by a number of studies in B.C. (Hammond 1978, Smith and Wass 1979), it has not been used in B.C. due to resistance by the forest industry. In fact some of the work paid for by the MoFL in B.C. has been adapted for use in the U.S., and remains unused here in B.C.(Hammond 1982, Garland 1982).

Table 8.1: Percentages of harvested area occupied by skidroads in areas with designated skidroads vs. "operator's choice".

OPERATOR CHOICE	PLANNED & DESIGNATED	COST CHANGE	SOURCE
17	9	+/-1%	Olsen & Seifert 1984
22	4	+29%	Bradshaw 1979
26	10	+/-0%	Froehlich *et al.*1981
16	3	*	Hammond 1984a

Training and supervision of operators is of primary importance (Adams *et al.* 1985). Olsen and Seifert (1984) report that there was a 20% difference in cycle time between two operators in their study. Froehlich *et al.* (1981) point out the importance of directional falling, and coordination between the faller and skidder operator to reduce winching. A recent trial in the Nelson Forest Region has demonstrated the need for close cooperation between the planner and the loggers to ensure that the operation actually follows the plan (Hammond 1984a). Planning is of no value without supervision to ensure the plan is carried out.

Reduced productivity due to compaction following partial cutting has also been reported (see table 6.2). For this reason, planned and designated skidroads are of prime importance in silvicultural systems which require multiple entries during the rotation. In these cases, the carefully laid out landings and skidroad networks become a part of the permanent harvest transport system, and would have to be removed from the productive land base.

8.2.4 Site preparation

The use of heavy machinery for site preparation can lead to extensive compaction. Use of low ground pressure movers, rear-mounted tilling equipment and restricting machine entry to times when soil moisture is low will minimize the risk of compaction. Studies like McMinn (1974) have demonstrated the advantages of systems which accomplish mixing rather than scalping.

There is a clear need to evaluate the impacts of site preparation on soil properties and long-term growth, rather than only survival and establishment. These studies are needed prior to widespread application of a treatment, not after.

Silvicultural planning and coordination between harvesting systems and regeneration objectives are crucial to control of soil degradation from mechanized site preparation. Improved utilization and prompt reforestation can minimize the need for site preparation. Herring and McMinn (1980) demonstrate that doing nothing can sometimes be superior to intensive site preparation. Due to the direct and indirect costs of site preparation, every effort should be made to harvest and reforest in such a way as to avoid the need for site preparation. As Haines *et al.* (1975) state: "Do as much as necessary but do as little as possible."

8.2.5 Broadcast burning

The potential adverse impacts of broadcast burning can be reduced by avoiding burns on sites where nutrient and organic matter losses are critical, and by carefully controlling the intensity of the burn. Again, long-term soil productivity has to be weighed against short-term gains in survival and seedling growth.

8.2.6 Erosion

Increased erosion rates are primarily the result of road construction, mineral soil exposure and vegetation removal. Reduction in all of these practices will reduce degradation due to erosion. Site preparation which creates bare mineral soil should be restricted to level ground and create only small discontinuous patches of bare soil.

Improved road location, construction techniques, drainage structures, and maintenance will all reduce erosion. Abandoned roads should be "put to bed" by restoring natural drainage courses, waterbarring and revegetation. An excellent review of various techniques to reduce road associated erosion has been prepared by Megahan (1977).

8.2.7 Pesticides

As with other silvicultural treatments, better planning and prompt reforestation can reduce the need for herbicide treatments. Brush species need to be examined as to their beneficial role in the forest environment such that vegetation control is not just another treatment that produces short-term gains in growth at the expense of long-term productivity. Nitrogen fixation and the production of organic matter are important processes in maintaining forest soil productivity. When herbicide use is necessary, methods which are species specific should be employed, rather than broadcast spraying. The use of insecticides and other chemical treatments can be minimized by careful species selection and wise stand management.

8.3 COSTS OF PREVENTION

The costs of prevention are as difficult to quantify as the potential costs of soil degradation itself. For sites prone to mass wasting, the costs of prevention may mean foregoing timber harvesting. These costs could run into the tens of thousands of dollars per hectare. In situations where the application of inappropriate silvicultural techniques would result in reduced productivity, avoiding soil degradation would result in a cost saving (Herring and McMinn 1980).

Soil or terrain inventories, when used as a basis for planning of harvesting and silvicultural operations can lead to substantial reductions in soil degradation. Detailed terrain and soil mapping costs are in the tens of dollars per hectare, which is slight compared to other costs. For example, the benefit of avoiding one mass failure on a road could easily pay for mapping a five thousand hectare watershed. A comprehensive system of inventory, planning and layout proposed by Hammond (1986a and 1986b) is estimated to cost between fifty and four hundred dollars per hectare.

Cable harvesting systems have been shown to have substantially higher costs compared to conventional ground skidding, however they do generally result in decreased levels of disturbance. A recent study in the Cariboo has shown cost increases of 80% for highlead and 20% for small crawler tractors over the cost of conventional skidder-crawler-tractor operations. The total disturbance levels were 9%, 23% and 34% for cable, small tractor and convention skidding respectively. Wellburn (1975) estimates that cable systems can cost as little as 15% more than conventional ground skidding under ideal conditions, and up to more than double under poor conditions. Conditions which affect cost are equipment suitability, crew performance, yarding distance, piece size, volume per hectare, and length of logging season.

Table 8.1 summarizes cost and disturbance data from various trials of planned and designated skidroads. This is probably one of the most cost effective methods of reducing harvesting soil degradation. Again there are numerous factors which can affect cost, such as piece size, terrain, and operator efficiency (piece size and winching distance increased the costs outlined by Bradshaw (1979). Most of the studies have shown close to a 50% decrease in disturbance with no increase in cost. There is the possibility to fine-tune the balance between costs and disturbance levels by adjusting skidding and winching distances (the prime cost factors) during the layout phase.

9.0 REHABILITATION OF DEGRADED SOILS

9.1 INTRODUCTION

Rehabilitation of degraded forest soils can be defined as the process whereby changes in soil characteristics, which are limiting to forest growth, are ameliorated to pre-disturbance levels. The changes in soil properties most often mentioned as resulting from forest soil degradation are a reduction in available nutrient capital or a change in soil physical properties, mainly increased bulk density. When caused by erosion, soil degradation is also associated with off-site damage, such as decreased water quality and impacts on fisheries resources.

Forest soil rehabilitation should not be confused with *site rehabilitation,* a term used by silviculturists to describe the process whereby a site that is not sufficiently restocked (NSR), or stocked with undesirable species, is brought back into production by the establishment of a suitable species. As discussed in section 5.2 in some cases the methods used to rehabilitate a site may themselves be the *cause* of soil degradation, even when there is an improvement in seedling survival and/or short-term growth (Ballard 1986, Haines *et al.* 1975).

Most soil rehabilitation to date in B.C. has been done at the insistence of parties suffering off-site damage. In these cases, the objectives of the rehabilitation measures fall short of those given in the definition above. The objectives are often limited to establishing vegetation, stabilizing the site, and limiting sediment production. Restoration of forest productivity is often secondary (Carr 1986e). These processes of rehabilitation are often a first step to restoring forest productivity, but often fall short of producing a crop in the next rotation.

For the purpose of this discussion, rehabilitation will be restricted to the improvement or amelioration of soil properties which are indicated as potentially limiting to forest productivity.

9.2 METHODS OF SOIL REHABILITATION

The methods of soil rehabilitation most often used for revegetation and stabilization of erosion sites include grass-legume seeding, mulching, fertilization, and planting with shrubs or hardwood trees. Hydroseeding often includes slurries of grass-legume mixes, fertilizer and mulch, and can sometimes incorporate soil stabilizer compounds. When these methods are applied for erosion control they are termed `bioengineering'. For more detail consult: Schiechtl 1980, Carr 1980, Homoky 1984 or Marchant & Sherlock 1984. There are also some ongoing studies to examine the possibility of reforesting landslide areas with conifers, generally in combination with the methods mentioned above (Beese 1986b). In all these methods the primary goal is to establish vegetation which will help to stabilize the site, and eventually renew soil health through gradual additions of organic matter. These can be quite successful in ameliorating soil degradation in depositional areas of landslides.

The scarp zones of landslides and gullies suffer not only from scalping and loss of nutrients, but also exposure of bedrock or compacted subsoil horizons. Because these zones are often still eroding, treatment cannot be applied to relieve the problems of high bulk density. Studies from the U.S and B.C. indicate that conifers which do establish on landslides generally have substantial reductions in productivity, and these effects are not likely to be ameliorated over the first rotation (Miles *et al.* 1984 & Smith *et al.* 1984, 1986). However the steps taken above are certainly a first step in restoring productivity.

Rehabilitation of soil degradation associated with timber harvesting and silvicultural practices employs somewhat different techniques. These sites are usually more amenable to mechanical treatment than erosion scars. Numerous techniques of tilling have been attempted to reverse the adverse effects of compaction and puddling (Terry and Campbell 1981). The winged subsoiler appears to be the most successful piece of equipment for most forest sites in the Pacific Northwest and B.C.(Andrus and Froehlich 1983, Carr 1986b). Brush blades are by far the least effective because they do not loosen the soil at depth. These treatments also require that soil nutritional and organic matter losses be restored through fertilization, respreading of soil previously removed and planting of grass-legume mixtures (Carr 1986a). Organic matter losses are significant not only to the overall nutrient capital of a site, but also to the formation of stable soil aggregates which will reduce soil density.

Without the application of soil rehabilitation treatments, degraded sites will eventually recover naturally. Freezing and thawing, wetting and drying, weathering, revegetation and incorporation of organic matter will tend to restore soil fertility over time. These natural processes can take decades or even centuries in the case of severely disturbed areas (Wert and Thomas 1981, Herring and McMinn 1980).

9.3 BENEFITS OF REHABILITATION

The benefits of soil rehabilitation are poorly understood at present. Most researchers do not expect that present techniques of rehabilitation are capable of restoring full site productivity

(Andrus and Froehlich 1983, Carr 1986e). However, studies have shown that tilling and other treatments can restore a major percentage of growth losses (Froehlich and McNabb 1983). The benefits of tilling in particular seem to depend on specific site characteristics and the ability to restore organic matter content, such that recompaction does not occur.

The benefits, however, have to be considered in light of consequences of not doing rehabilitation. The effects of scalping and compaction are long-lasting, and will clearly affect forest productivity. Waiting for natural rehabilitation will cause reduced yields, extended rotation ages, and in the case of erosion, lead to further damages to other resources.

9.4 COSTS OF REHABILITATION

Due to the lack of an operational program of rehabilitation, it is impossible to accurately assess the costs. Hammond (1985 & 1986b) estimated costs varying from $2,500 to $4,000 per hectare for severely disturbed areas with active erosion. He included treatments such as stabilization of eroding areas, restoration of drainage, revegetation and tilling. In Prince George, operational trials of landing rehabilitation average about $750 per hectare. This includes: ripping with the winged subsoiler, respreading top soil, fertilization and seeding with a grass-legume mixture (Mcleod 1987). Andrus and Froehlich (1983) presented costs for tilling of skid trails ranging from US$80 per hectare for a rock ripper to US$370 per hectare for a brush blade. The winged subsoiler had a cost of US$325 per hectare.

Costs can be expected to vary, depending on individual site characteristics, access and availability of equipment, as well as the type and degree of degradation.

9.5 REHABILITATION PROGRAMS IN B.C.

Until recently, the majority of rehabilitation effort has been concentrated on eroded areas because of their effect on other resources (Carr 1986e). These studies have emphasized revegetation to control erosion and limit sediment production (Carr 1985a and 1985b, Homoky 1984, Marchant and Sherlock 1984).

Some landing rehabilitation trials have been established in the Cariboo Forest Region (Mitchell 1982). More recently the Prince George Forest Region has initiated a number of trials in rehabilitation of landings (Carr 1986c and 1986d), however little work has been done in other regions. If rehabilitation is cost-effective, it is obvious there should be more emphasis on rehabilitating sites directly degraded by forest harvesting practices, as they are the largest single contributor to the degraded area (see table 5.11). There is a clear need for ongoing long-term research into methods, costs and potential benefits of forest soil rehabilitation. The limited results and high cost of rehabilitation also indicates the need for more emphasis on prevention of soil degradation.

10.0 DISCUSSION OF OPTIONS

10.1 INTRODUCTION

In B.C. there are significant areas with degraded soils caused by past forestry practices. Soil degradation is still occurring due to current forestry practices.

Effective forest management requires appropriate access to the land. These access corridors may be non-productive in the short or long-term. For this reason, it is clear that a balance must be struck between the proportion of land dedicated to access and to production in order to achieve a maximization of land productivity as a source of wood products. Overly restrictive harvesting practices may make the forest resource economically unavailable whereas unrestrictive practices may result in unacceptable forest productivity losses and/or unacceptable damages to other resources.

10.2 EXISTING AND FUTURE SOIL DEGRADATION

10.2.1 Existing Soil Degradation

Data presented in Chapter 6 provides estimates for the current or existing situation regarding potential productivity losses. With respect to these estimates, one thing is clear. Due to a lack of specific information and acceptable economic models, it is not possible to provide a definitive answer regarding the cost of soil degradation. However, it is also clear that productivity losses are occurring throughout the Province. As previously indicated in Chapter 6, the present annual forest productivity loss that is occurring as a result of soil degradation caused between 1976 and 1985/1986 is estimated at over 400,000 cubic metres annually.

Costs for the rehabilitation of degraded soils can be high. For example Hammond (1985) estimated costs ranging from $2,500/ha to

$4,000/ha. Preliminary results from reviewing unpublished data and responses to the questionnaire show a range of $1,000/ha to $5,000/ha depending upon the method used and the type of terrain. In addition to high rehabilitation costs, it should be noted that the full recovery of productivity on degraded soils is questionable (Carr 1986c).

The application of an economic analysis to this situation will, depending upon the method used, show that the costs of rehabilitation are essentially unaffordable for most sites. That is, the direct economic benefit derived from rehabilitating the site is less than the cost. However, this tenet must be viewed from both the perspective of the land owner (the Crown) as well as industry. Given that there are costs (and benefits) related to the rehabilitation of existing soil degradation, the central issue is how to equitably share them between government and industry. One could argue that industry is already paying a fair price for the timber and that additional costs incurred today will give benefit mainly to the land owner through the maintenance of future yields and other values. Consequently, the land owner should pay the cost of rehabilitation. On the other hand, one could argue that industry is not paying a fair price for the timber and that they too will benefit from the rehabilitation of degraded sites since forest productivity will be maintained. At present, some recognition is now given in the stumpage appraisal cost allowances, whereas at one time no allowances were made. However, it is difficult to comment on the adequacy of these allowances.

One of the central issues regarding the rehabilitation of past soil degradation has been a lack of understanding of the magnitude of the problem. This appears to have resulted in a lack of political and hence financial will to address the issues, (Hammond 1985, Carr 1986c). If it can be agreed that rehabilitation of degraded sites is a cost of doing business in the context of reforestation, then there will need to be some major changes made to MoFL policy to accommodate this requirement (this aspect will be discussed in Phases II and III of this project).

10.2.2 Future and Long-Term Soil Degradation

The same points raised in the previous section regarding past or existing soil degradation issues and the issue of `who should pay' are valid here as well. However, regardless of who pays, the issue is that forest productivity is declining as a result of soil degradation. The trends have been established such that if the forests are harvested and managed in the future the same as is being done today, the loss of productivity resulting from soil degradation will continue at least until the end of the first pass. In fact, the trend is likely to greater loss of productivity since a greater proportion of the provincial cut is coming from areas of steeper slopes. It has been estimated (see Chapter 6) that the annual forest productivity loss resulting from soil degradation is increasing approximately 50,000 cubic metres per year. If present trends continue, by the year 2000, the productivity loss may exceed one million cubic metres per year. This could represent an annual loss of over 200 million dollars to the provincial economy.

As pointed out by Carr (1983), it is necessary to compare the costs of prevention with the costs of rehabilitation. Most authors on the subject have concluded that the prevention of degradation is less costly than rehabilitation (Hammond 1986b, FERIC 1980, Smith and Wass 1985). For example, from a review of existing literature and results of the questionnaire, costs for utilizing alternative harvesting systems to reduce soil degradation factors such as erosion and compaction are in the range of $250/ha to $1,800/ha. Such costs are considerably lower than those reported for rehabilitation.

Effective planning and policy regulation are the necessary tools for the prevention of soil degradation. Such planning might include the gathering of information on soil characteristics and drainage, the choosing of equipment to harvest the site, or the use of planned and designated skidroads (Froehlich *et al.* 1981). It has been suggested by Hammond (1986b) that comprehensive planning costs including forest inventory, ecosystem mapping, engineering analysis, and layout are in an approximate range of $200/ha to $405/ha. Some studies (Froehlich *et al.* 1981, Olsen and Siefert 1984) have, in fact, shown that planned skidroads add nothing or an insignificant amount to the harvesting costs. Clearly, planning as a tool to prevent soil degradation is a cost efficient method when compared to the costs of rehabilitation. Such planning will also assist in the optimization of equipment use. For example, it will be possible to know where alternate harvesting systems are required (e.g. using cable systems as opposed to skidding) so that the additional costs for these systems are only applied where required (FERIC 1983).

10.3 CONCLUSIONS

Past forestry practices have resulted in a reduction of forest productivity due to soil degradation. The magnitude of this loss of productivity has been examined in other chapters of this report and been demonstrated to be potentially significant. A lack of specific data impairs the ability to achieve an accurate estimate. Depending on the economic models used, the rehabilitation of degraded soils can be cost justifiable, at least in some circumstances. However, the aspect of who should pay remains a serious issue.

Soil degradation is still occurring due to forest harvesting and silvicultural practices and the effects of this potential loss of productivity will have long-term consequences. The lack of recognition of this situation by government and industry remains as one of the most significant issues. The most effective means of keeping all possible growth-reducing impacts to the lowest possible economic level is planning. Effort is required for the identification of sensitive soils and the planning of harvesting systems that will eliminate or reduce impacts. As a case in point, the use of planned and designated skidroads has been shown as a very effective planning tool. As a corollary to this, forest land management policies and adequate enforcement are required to effectively control and prevent future soil degradation.

As a final point, it must be stressed that site specific data is necessary when discussing the effects of soil degradation resulting from various forms of timber harvesting and silvicultural treatments. In the case of a silvicultural practice such as windrowing, foresters require a thorough understanding of its long-term consequences on productivity before implementing the technique on an operational basis. In effect we have paid for a silvicultural practice which is going to result in lost productivity. The important point here is not to repeat past mistakes. It is necessary to research these methods thoroughly before putting them into operation.

11.0 SUGGESTIONS FOR PHASES II AND III OF THE PROJECT

As outlined and discussed in Chapter 1 of this report, the central objectives of Phase I of the study program were to evaluate the relationship between soil degradation and forest productivity, to express this relationship in terms of potential loss of conifer productivity on a volume and dollar basis, and to investigate the feasibility and costs associated with the rehabilitation of site productivity.

The working plan for this project justifiably indicated that the scope of Phases II and III will depend on the nature of the results generated by Phase I (the contents of this report). It has been suggested that the results of this report will be used to formulate more succinct terms of reference for Phases II and III of the problem analysis.

At present, Phase II is intended to outline appropriate research needs and strategies and Phase III will examine current government regulations, legislation and policies as well as the adequacy of staffing and training in government and the private sector related to soil degradation and rehabilitation. As with any project of this type, some tasks overlap between phases. Consequently, some discussion is provided in this report and some literature is reviewed which deals more specifically with Phase II and III. Consequently, through the course of completing this Phase I report, we have generated some ideas, concepts and concerns which may prove useful in refining the working plan for Phases II and III.

The following points summarize our thoughts in this regard:

1. In several cases, data available from the Ministry of Forests and Lands regarding area summaries for factors such as harvest method and site preparation were found limiting and incomplete. Consequently, our analysis of the data was influenced.

We suggest that some effort (minor), on behalf of the authors in cooperation with personnel in the Ministry of Forests and Lands, be undertaken in Phase II of the project to fine-tune this data base (where possible) so that greater confidence can be placed on the data.

2. Some effort should be directed toward the elucidation of covert (or immediately unrecognizable) soil degradation and its affect on productivity. We believe this may be a significant issue regarding tree growth since by utilizing measurements of productivity to determine the degree of soil degradation we may ignore the fact that the site is not at optimum potential.

3. Although the basic subject of the problem analysis entails an assessment of the role soil plays as an environmental variable influencing site productivity, other very significant (perhaps even more significant in some cases) factors must be considered. These other factors, such as reduced vegetative competition and increased biological activity, can play a compensatory role and until this is determined, total productivity effects cannot be determined.

4. In order to provide some specific insight into the formulation of research needs, it is suggested that more effective results can be achieved by examining selected portions of the province rather than the province as a whole. We believe that this will allow a more detailed analysis of available data and research to be undertaken as well as increase the necessary communication with regional foresters and soil scientists. In the absence of taking this more specific approach, we feel that the research issues identified will tend toward so called `motherhood issues' rather than real operational concerns.

One of the more significant issues related to the need for greater specificity is the requirement to examine, in detail, the manner by which TSA analyses account for soil degradation. We have found a significant divergence of opinion in this regard throughout the Province. Due to its implications, this issue needs to be elucidated carefully.

5. Issues related to economic analysis of productivity losses require examination. The economic fraternity appears somewhat divided (or unsure) of the appropriate means of dealing with the issue. Some appear to favor the `net present value' approach whereas others seem to lean toward using an `allowable cut effect' approach (reduction of AAC). In the absence of a resolution to this question, it is difficult to determine the so called `cost-effectiveness' of site rehabilitation.

6. We suggest that, following a review and edit of this Phase I report, a workshop be organized and undertaken to discuss and debate the methods and findings. This need not be a large undertaking, and perhaps would be most effective if the workshop attendees are restricted to a select few, representing various areas of the province, specific disciplines and from both government and industry. In our opinion, this workshop will be most beneficial in setting the stage for Phases II and III of the problem analysis.

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APPENDIX I
QUESTIONNAIRE FORM AND RESPONSES

QUESTIONNAIRE

EVALUATION OF SOIL DEGRADATION AS A FACTOR EFFECTING N.S.R. BACKLOG IN B.C.

Name of Respondent ______________________________

Position/Agency ______________________________

Address ______________________________

Phone Number ______________________________

1. Please list any existing or ongoing studies and/or data that you are aware of regarding soil degradation in your Region.

   We are interested in any and all information related to causes and effects as well as methods of rehabilitation and prevention.

   1. ______________________________
      ____
   2. ______________________________
      ____
   3. ______________________________
      ____
   4. ______________________________
      ____

2. Please list any studies or data regarding soil degradation that you feel are applicable to your area but were undertaken outside of B.C. For example, the U.S., Alberta, Ontario, Quebec or Europe.

   ____
   ____
   ____
   ____
   ____
   ____
   ____
   ____

3. Given that the major factors of soil degradation are:

	% reduction or increase in productivity (min-max)
1. soil density increase	
2. soil moisture decrease/increase	
3. soil nutrient decrease	
4. loss of surface organic matter	
5. soil acidity increase/decrease	
6. soil erosion and mass movement	
7. increase/decrease in soil bacteria/nematode/actinomycetes	
8. increase in frost depth and/or frost heaving	

From your best guess based on personal experience, or knowledge acquired from the literature, please indicate what you feel is the effect in your Region on conifer productivity for each soil degradation factor (assuming there has been a significant change in soil properties for that factor). This is best given as a % reduction (or increase) in conifer productivity for each factor.

4.1 Please indicate what you feel are the most significant soil degradation processes in your region in decreasing order of importance (please feel free to add any factors which you may feel we have missed).

4.2 Do you feel that there is a significant link between soil degradation and backlog NSR in your Region.
If so, what are they?

4.3 Do you feel soil degradation on re-stocked lands (ie. non NSR) is having a significant effect on soil productivity?
If so, should it be reflected in the calculations of AAC.?

5. Based on your knowledge and experience could you please provide us with your opinion as to the amount and type of soil/site degradation caused by various treatments, as applied in your Region.

Type of Treatment	Types of Degradation	% of treated area affected
1. Ground Skidding		
2. Cable Logging		
3. Broadcast Burning		
4. Windrowing/Bunching		
5. Scarification		
others 6.		
7.		
8.		
9.		

6. Related to #5 above, please indicate to the best of your knowledge, the methods and costs for prevention of soil/site degradation and for site/soil rehabilitation on a hectare basis.

Type of Degradation	Means of Prevention	Costs of Prevention ($/ha)	Rehabilitation Method	Costs of Rehabilitation ($/ha).

7. Could you please provide us with a list of contacts (government and industry) in B.C., Canada, and/or the U.S. Pacific Northwest who you feel may have information regarding soil/site degradation.

8. Other comments

DISCUSSIONS OF RESPONSES TO QUESTIONNAIRE

1. The questionnaire was sent to 26 individuals; 19 government and 7 industry.

2. A total of 18 responses were received.

3. Of the 18 responses, 8 were from the coast and 10 from the interior.

4. The following list ranks soil degradation factors according to questionnaire respondents from most severe to least severe and provides the range of productivity reduction as a percentage:

Soil density increase	5-25%
Soil erosion/mass movement	1-30%
Loss of organic matter	5-20%
Soil moisture increase/decrease	0-15%
Soil biota changes	0-14%
Soil acidity changes	0-10%
Increase in frost depth	0-5%

5. Respondents from industry tended to estimate lower productivity losses than government respondents; respondents from the coast tended to record lower values for productivity losses in comparison to respondents from the interior.

6. 75% of respondents felt that there is no direct link between soil degradation and backlog NSR; 25% felt that there is some connection.

7. 92% of all respondents felt that soil degradation is having a significant effect on conifer productivity; 8% said there wasn't or that more information is required.

APPENDIX II
ALTERNATIVE PRODUCTIVITY - LOSS CALCULATION

APPENDIX II: ALTERNATIVE PRODUCTIVITY-LOSS CALCULATION

The calculations of decreased forest productivity presented in this appendix are based on the same methods used in Chapters 5 and 6. The differences are in the assumptions of percentages of degraded soil area and yield reductions resulting from that degradation (see tables II.1, II.2 and II.3). The calculations presented previously were conservative interpretations of the available data. The assumptions made here are equally plausible interpretations of the existing data, but not conservatively biased.

Modifications to assumptions employed in Chapters 5 and 6 are summarized as follows:

- estimates of harvested area degraded by ground skidding are increased by 3%.
- the percent growth reduction due to soil degradation resulting from harvesting is increased to 60% on the coast and 75% in the interior.
- an additional 10% of the broadcast burned areas are included as having a 20% reduction in growth.
- 5% of the areas receiving "Other Mechanical Site Preparation" are included as having degraded soils.

These alternative assumptions include consideration of factors felt to be likely, but not proven with existing data. For example, the percent area severely disturbed by ground skidding, reported from studies in B.C., ranges from 14 to 58 percent (see table 5.1), with the majority between 20 and 40%. The percentages chosen here are still within that range.

The percent growth changes on skidroads presented in table 6.1 range from -26 to -95% for the impacted area. The studies indicated that in most cases there is a decrease in the size of individual trees, as well as a decrease due to stocking reductions. For the estimates presented here, it is assumed that the decreased size of trees results in further yield losses because many trees on the skidroads are of unmerchantable size when the cutblock has reached rotation age (alternatively the rotation age could be extended also resulting in further long-term yield reductions). For the coast where trees are generally larger, the growth reduction is set at 60%, as opposed to 75% for the interior.

The addition of another loss category for slashburning is to account for long-term site productivity losses of a minor nature from reductions in organic matter and nitrogen. The "other mechanical site preparation" losses likely result from compaction and/or scalping from some types of machinery or operations on moist soils.

These minor adjustments in assumptions have increased the estimated area degraded by forestry practices between 1976 and 1985/86 by 18%, the annual yield losses by 55%, and the current annual loss to the provincial economy to $126 million (see tables II.4 and II.5). Assuming similar forestry practices and levels of soil degradation, the annual loss to the provincial economy could exceed $200 million by the year 1991. Given the limited nature of the data available at present, the losses due to forest soil degradation could very well be of this magnitude.

Table II.1: Percentage of harvested area degraded by various harvesting systems* on specified slope classes (assumptions by the authors based on available literature).

	HELI >50%	CABLE <35%	CABLE 35-50%	CABLE >50%	LT FLOT <35%	LT FLOT 35-50%	GR WIN <35%	GR WIN 35-50%	GR WIN >50%	GR SUM <35%	GR SUM 35-50%	GR SUM >50%
COMPACT & DEEP DIST	3	10	10	10	18	20	18	20	23	25	28	28
ERODED	0.5	0.1	0.5	1.0	0.1	0.5	0.1	0.5	1.5	0.2	1.0	2.5
TOTAL DEG	3.5	10.1	10.5	11	18.1	20.5	18.1	20.5	24.5	25.2	29	30.5

*HELI=helicopter, CABLE=cable yarding, LT=light flotation, GR=ground skidding, WIN=winter, SUM=summer.

Table II.2: Percentage of treated area degraded by specified silvicultural practices (assumptions by the authors based on available literature).

	BURN HEAVY	BURN LIGHT	WINDROW	BUNCH	BLADE SCARIFY	DRAG SCARIFY	OTHER MECH	CHEMICAL
AREA DEGR	10	10	40	30	20	0	5	0

Table II.3: Percentage reduction in growth applied to degraded areas of each degradation class (assumptions by the authors based on available literature).

	HARV DEGR	EROSN DEGR	BURN HEAVY	BURN LIGHT	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	OTH MEC DEGR
COAST	60	100	50	20	50	50	50	50
INTERIOR	75	100	50	20	50	50	50	50

Table II.4: Estimate of the current annual growth losses (m3/yr) occurring on degraded soils as a result of forestry practices during 1976-1985/86 (derived from tables 5.4, 5.6, II.1, II.2, II.3 and MOF 1980).

FOREST REGION	TOTAL DEGR AREA (ha)	MAI m3/ha/yr	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	OTH MEC DEGR	TOTAL LOSS
						(m3/yr)				
VANC CST	43148	4.3	87392	5585	11128	127	741	300	83	105356
P RUP CST	7744	2.6	11830	418	*	*	*	*	*	12248
VANC INT	1965	2.8	4044	110	*	*	*	*	*	4155
P RUP INT	53945	1.5	44841	528	14076	522	1652	648	464	62731
PR GEORGE	159573	1.7	140142	1645	18443	6354	10995	6232	578	184389
CARIBOO	76703	1.4	68032	880	4906	104	3833	184	273	78211
KAMLOOPS	78939	2.0	87909	1350	3166	1139	10211	1926	353	106053
NELSON	54565	2.1	70291	1756	1809	290	4027	1915	130	80218
TOTAL	476582		514482	12271	53528	8536	31459	11204	1882	633362

Table II.5: Estimate of the current annual growth losses (m3/yr) occurring on degraded soils as a result of forestry practices during 1985/86 (derived from MOFLAR, tables 5.3, II.1, II.2, II.3 and MOF 1980).

FOREST REGION	TOTAL DEGR AREA (ha)	MAI m3/ha/yr	HARV DEGR	EROSN DEGR	BURN DEGR	WINDRW DEGR	BUNCH DEGR	BL SCAR DEGR	OTH MEC DEGR	TOTAL LOSS
						(m3/yr)				
VANC CST	5383	4.3	11468	733	1100	22	11	8	37	13379
P RUP CST	143	2.6	218	8	*	*	*	*	*	226
VANC INT	351	2.8	723	20	*	*	*	*	*	743
P RUP INT	7276	1.5	5065	60	913	395	209	26	116	6784
PR GEORGE	21480	1.7	15484	182	2796	1994	1084	642	129	22312
CARIBOO	9790	1.4	9313	120	161	65	166	1	122	9949
KAMLOOPS	8603	2.0	10597	163	382	85	525	259	42	12053
NELSON	6318	2.1	7630	191	356	139	676	111	17	9120
TOTAL	59344		60498	1475	5708	2700	2671	1048	465	74565

Table II.4: Estimate of the current annual growth losses (m3/yr) occurring on degraded soils as a result of forestry practices during 1976-1985/86 (derived from tables 5.4, 5.6, II.1, II.2, II.3 and MOF 1980).

FOREST TOTAL DEGR MAI HARV EROSN BURN WINDRW BUNCH BL SCAR DEGR OTH MEC DEGR TOTAL LOSS